

**KEYWORDS:**

Lubricant  
Fastener  
Red Lead  
Molykote P37

## **EVALUATION OF REPLACEMENT THREAD LUBRICANTS FOR RED LEAD AND GRAPHITE IN MINERAL OIL**

**WPAD-QES-ME-1206**

**T.L. Jungling, D.R. Rauth and D. Goldberg**

**April 30, 1998**

199808608 126

### **NOTE**

This document is an interim memorandum prepared primarily for internal reference and does not represent a final expression of the opinion of Westinghouse. When this memorandum is distributed externally, it is with the express understanding that Westinghouse makes no representation as to completeness, accuracy, or usability of information contained therein.

### **NOTICE**

This report was prepared as an account of work sponsored by the United States Government. Neither the United States, nor the United States Department of Defense, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

**Westinghouse Electric Company  
Plant Apparatus Division  
500 Penn Center Boulevard  
Pittsburgh, PA 15235-5713**

**DISTRIBUTION STATEMENT A**

Approved for public release;  
Distribution Unlimited

**DTIC QUALITY INSPECTED 5**

MAY-13-1997 06:26

P.03/04

**REPORT DOCUMENTATION PAGE**

OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

<b>1. AGENCY USE ONLY (Leave blank)</b>	<b>2. REPORT DATE</b> April 30, 1998	<b>3. REPORT TYPE AND DATES COVERED</b>
<b>4. TITLE AND SUBTITLE</b>  Evaluation of Replacement Thread Lubricants for Red Lead and Graphite in Mineral Oil		<b>5. FUNDING NUMBERS</b>  N00024-89-C-4003
<b>6. AUTHOR(S)</b>  T. L. Jungling, D. R. Rauth, D. Goldberg		<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  WPAD-QES-ME-1206
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Westinghouse Electric Company Plant Apparatus Division 500 Penn Center Boulevard Pittsburgh, PA 15235-5713		
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Department of the Navy Naval Sea Systems Command 2531 Jefferson Davis Highway Arlington, VA 22242-5160		<b>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</b>
<b>11. SUPPLEMENTARY NOTES</b>		
<b>12a. DISTRIBUTION / AVAILABILITY STATEMENT</b>  Statement A applies		<b>12b. DISTRIBUTION CODE</b>
<b>13. ABSTRACT (Maximum 200 words)</b>  Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGM). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials, sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGM. Therefore, it can be substituted directly for RLGM without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.		
<b>14. SUBJECT TERMS</b>  Lubricant, Fastener, Red Lead, Molykote P37		<b>15. NUMBER OF PAGES</b> 150
		<b>16. PRICE CODE</b>
<b>17. SECURITY CLASSIFICATION OF REPORT</b>  UNCLASSIFIED	<b>18. SECURITY CLASSIFICATION OF THIS PAGE</b>  UNCLASSIFIED	<b>19. SECURITY CLASSIFICATION OF ABSTRACT</b>  UNCLASSIFIED
		<b>20. LIMITATION OF ABSTRACT</b>  NONE

NSN 7540-01-280-5500

## ABSTRACT

Eight commercially available thread lubricants were evaluated to determine the best replacement for Red Lead and Graphite in Mineral Oil (RLGMO). The evaluation included coefficient of friction testing, high temperature anti-seizing testing, room temperature anti-galling testing, chemical analysis for detrimental impurities, corrosion testing, off-gas testing, and a review of health and environmental factors. The coefficient of friction testing covered a wide variety of factors including stud, nut, and washer materials, sizes, manufacturing methods, surface coatings, surface finishes, applied loads, run-in cycles, and relubrication. Only one lubricant, Dow Corning Molykote P37, met all the criteria established for a replacement lubricant. It has a coefficient of friction range similar to RLGMO. Therefore, it can be substituted directly for RLGMO without changing the currently specified fastener torque values for the sizes, materials and conditions evaluated. Other lubricants did not perform as well as Molykote P37 in one or more test or evaluation categories.

## Table of Contents

	<u>Page</u>
<b>Abstract</b> .....	i
<b>List of Figures</b> .....	iii
<b>List of Tables</b> .....	iii
<b>I. Introduction</b> .....	1
<b>II. Background</b>	
Objective .....	1
Overall Approach .....	2
<b>III. Experimental Procedures</b>	
Candidate Lubricants .....	2
Functional Testing .....	3
Coefficient of Friction Testing .....	4
Phase I Testing .....	4
Phase II Testing .....	5
Anti-Seizing Testing .....	5
Anti-Galling Testing .....	6
Detrimental Material Evaluation .....	6
Health and Environmental Evaluation .....	6
Corrosion Testing .....	6
<b>IV. Results And Discussion</b>	
Coefficient of Friction Results .....	9
Phase I Test Results .....	9
Phase II Test Results .....	10
Use of the Coefficient of Friction Data .....	13
Anti-Seizing Test Results .....	17
Anti-Galling Test Results .....	17
Detrimental Material Evaluation .....	18
Health and Environmental Evaluation .....	18
Corrosion Testing Results .....	19
<b>V. Conclusions</b> .....	20
<b>VI. Acknowledgments</b> .....	20

Appendix A	Equation for Calculating the Coefficient of Friction ( $\mu$ )
Appendix B	Summary Statistics of Coefficient of Friction Database of Replacement Candidates for Red Lead And Graphite in Mineral Oil (RLGMO)
Appendix C	Coefficient of Friction Data for the Phase II Test Assemblies
Appendix D	Anti-Seizing Test Results
Appendix E	Anti-Galling Test Results

## List of Figures

Figure 1	Skidmore-Wilhelm Torque Tension Unit, Model RL .....	21
Figure 2	Typical Fastener Assemblies: 1.5-8UNC-2A Monel K-500 (Alloy Code MA) and 0.75-10UNC-3A Alloy 625 (IMC3) .....	21
Figure 3	Coefficient of Friction Ranges of the Phase I Lubricants .....	22

## List of Tables

Table 1	Test Lubricants and Qualitative Composition .....	3
Table 2	Corrosion Test Alloy Combinations .....	6
Table 3	Coefficient of Friction Ranges (90/95 Tolerance Interval) .....	9
Table 4	Coefficient of Friction Range (excluding Alloy 625) .....	10
Table 5	Run-in Coefficient of Friction Values .....	14
Table 6	Design Coefficient of Friction Values .....	15
Table 7	Key to Tables 5 and 6 .....	16

## Evaluation of Replacement Thread Lubricants For Red Lead And Graphite in Mineral Oil

### I. Introduction

Westinghouse uses hundreds of bolted closures on power plants, employing fastener materials including high-strength alloy steels, nickel-based alloys, copper-nickel, austenitic stainless steels and aluminum alloys. Since many of these fasteners rely on torque to establish precise preload stresses in the bolted closure, the thread lubricant must be well characterized with a predictable and narrow coefficient of friction range. For closures in some high temperature systems the purity of the lubricant is essential. The lubricant must contain very low levels of detrimental materials, such as mercury, sulfur, phosphorus, halogens and low melting point metals. Also, in high-temperature systems the lubricant must possess adequate anti-seizing properties to permit disassembly and maintenance of the hardware.

Other characteristics of concern relate to the health and environmental aspects of the lubricant. Lubricants are used in confined spaces; therefore, they must have minimal toxicity to the workers both during initial application and at elevated temperatures where volatile toxic gases may be produced. Lubricants that are considered environmentally hazardous will result in additional disposal cost at the end of life.

### II. Background

For more than 20 years Westinghouse has specified the use of Red Lead and Graphite in Mineral Oil (RLGMO) per the Military Specification MIL-L-24479 as a thread lubricant for fastener applications, including closure fasteners on high-pressure and high-temperature components. Many of these fasteners rely on torque to establish precise preload stresses. RLGMO has provided a predictable and narrow coefficient of friction range, resulting in excellent performance. Based on testing with a limited number of fastener alloys, the design coefficient of friction range of RLGMO was established to be from 0.05 to 0.11. This range has proven to be narrow enough so that a single torque value can be assigned to a fastener design. Based on analysis, a single torque value can produce an installation load will not exceed the design stress limits on the fastener while achieving the necessary preload for operation.

However, concerns regarding the hazardous nature of lead both to the worker and for eventual disposal of hardware, as well as more restrictive environmental regulations regarding the use of lead, prompted Westinghouse to evaluate, qualify, and prepare a specification for the procurement of a non-hazardous commercial lubricant as a replacement for RLGMO. As a secondary objective, Westinghouse evaluated if the replacement lubricant could also replace a second widely used thread lubricant, Molybdenum Disulfide in Isopropanol (MDSI). MDSI is used interchangeably with RLGMO on many alloy steel fasteners as well as in high temperature applications on nickel-based alloys.

### Objectives

The objective of the original phase of testing was to evaluate and identify a non-hazardous commercial lubricant to replace RLGMO, possessing a coefficient of friction range which duplicates that of RLGMO. The objective of the second phase of testing was to expand the coefficient of friction database for the selected lubricant with additional alloy combinations, fastener sizes and manufacturing methods. This report summarizes the process used to select the replacement lubricant and provides the coefficient of friction data for use with this lubricant.

### **Overall Approach**

Based on a review of product literature and material safety data sheets (MSDS) for 14 commercially available anti-seizing lubricants, eight candidate lubricants that did not contain obvious detrimental materials were selected for testing as potential replacements. These lubricants fell into three broad categories based on their anti-seize additives: nickel-based, copper-based or metallic-free. In addition to the eight candidate lubricants, both RLGMO and MDSI were included in the test plan to act as controls and provide comparisons to current experience.

In order to select a suitable replacement for RLGMO and MDSI, the following characteristics (acceptance criteria) were evaluated:

- ▶ Coefficient of friction range (similar to the established range for RLGMO, that is, 0.05 to 0.11).
- ▶ Anti-seizing capability (preclude seizing after service at temperatures up to 650°F).
- ▶ Anti-galling capability (preclude galling of fasteners at ambient temperature during initial torquing).
- ▶ Detrimental material content (less than 250 parts per million (ppm) of low melting point metals, halides, sulfur, and phosphorus and less than 10 ppm of mercury).
- ▶ Health related concerns (minimal worker safety precautions required and no release of toxic gases during heating).
- ▶ Environmental concerns (that is, it is not a hazardous material relative to disposal).
- ▶ Corrosivity (that is, it will not cause general or localized corrosion or exacerbate stress induced corrosion of the fastener or adjacent materials).

After this evaluation had been completed and the replacement lubricant determined, additional coefficient of friction testing was conducted to expand the database to a number of prototypic fastener combinations.

### **III. Experimental Procedures**

#### **Candidate Lubricants**

A compositional summary of the 10 lubricants evaluated is given in Table 1. The compositions listed were based on manufacturer's literature as well as the corresponding MSDS.

**Table 1 Test Lubricants and Qualitative Composition**

LUBRICANT		COMPOSITION, PERCENT			
No.	Manufacturer, Name	Copper	Nickel	Graphite	Other
1	<b>Fel Pro, N5000, High Performance</b>		20	25	
2	<b>Fel Pro, N1000</b>	20		25	
3	<b>Huron, Neolube No. 650</b>			40-60	25-50 Mineral Oil 2-25 Petrolatum
4	<b>Jet Lube, NIKAL, Nuclear Grade</b>		30		Polyisobutene
5	<b>Fel Pro, N2000, High Purity</b>	25		20	25 Petroleum Distillates
6	<b>Bostik, Never Seez - Ni/Nuclear Grade</b>		18		Talc Bentone Grease
7	<b>Lub-O-Seal, NM-91 Anti-Seize, Nuclear Grade</b>			unknown	
8	<b>Dow Corning, Molykote P37 Paste</b>			21	50 Mineral Oil 14 Calcium Hydroxide 9 Zirconium Oxide 1 Silica
9	<b>Molybdenum Disulfide in Isopropanol (MDSI) MIL-L-24478</b>				60 Molybdenum Disulfide 40 Isopropanol
10	<b>Red Lead and Graphite in Mineral Oil (RLGMO) MIL-L-24479</b>			16	60 Lead Oxide 24 Mineral Oil
	<b>Fel Pro, N7000 (Phase II testing only)</b>			20	25 Calcium Oxide

### Functional Testing

A test program was developed to evaluate each lubricant's coefficient of friction, anti-seizing, and anti-galling capability. This testing was designed to provide a statistically significant database on all ten lubricants so that comparisons could be made between the candidate lubricants, RLGMO and MDSI. These comparisons of performance would form the basis for the best replacement for RLGMO and possibly MDSI. For the evaluation of anti-galling and anti-seizing resistance three material combinations were used: Type 304 (Unified Numbering System (UNS) S30400) stainless steel studs and nuts, alloy steel (AISI 4140 - Grade B7 (UNS G41400)) studs and carbon steel (UNS K04002) nuts and Monel K-500 (UNS N05500) studs with Monel 400 (UNS N04400) nuts. The stainless steel combination was judged most likely to result in galling for a poor or marginal lubricant. These combinations allow the evaluation of actual fastener materials

as well as assuring test "failures", so that the candidate lubricants can be ranked. Due to the relatively low usage of stainless steel fasteners in actual hardware, Alloy 625 (Inconel 625 - UNS N06625) studs and nuts replaced the stainless steel combination in the coefficient of friction testing. This phase of testing also included the K-500/Monel 400 combination as well as both bare and phosphate coated alloy steel studs. The studs were 3/4-10UNC-2A with rolled threads. For the above combinations, hardened carbon steel washers were used to represent a prototypical bearing surface. The washers were fixed so they could not rotate during the test which could have resulted in erroneous coefficient of friction values. For each test a new (previously unused) stud, nut, and washer were employed.

Prior to testing, the studs, nuts, and washers were cleaned in sequential baths of trichloroethane and acetone and dried. Studs were visually inspected for burrs and defects which could lead to premature galling during the tests. Studs and nuts were assembled by hand to ensure that there was no interference or binding prior to testing. Each test assembly and its individual components were engraved with a unique identification number representing the alloy, the lubricant, and the test set number.

### Coefficient of Friction Testing

#### Phase I Testing

Two Skidmore-Wilhelm Torque Tension units equipped with calibrated load cells, shown in Figure 1, were utilized for measuring the load on the test assembly. Typical test assemblies are shown in Figure 2. For each material/lubricant combination, five duplicate test assemblies were loaded in five equal increments up to a load value equivalent to 2/3 of the stud material minimum yield strength. At each increment the torque value was recorded. Each loading cycle was repeated four times. The four loading cycles were defined as follows:

Cycle A (Run-In)	Representing a new, unused fastener torqued for the first time.
Cycle B (Design)	Representing a fastener having been subjected to a previous torquing cycle, disassembled, additional lubricant applied and retorqued. This generally represents actual fastener installation practice, and is considered most prototypical.
Cycle C (Used Stud Run-In)	Representing a used fastener that has been removed from the original hardware, cleaned, relubricated and retorqued.
Cycle D (Used Stud Design)	Representing a used fastener that has been removed from the original hardware, cleaned, relubricated, retorqued once, disassembled additional lubricant applied and retorqued again, that is, a used fastener subjected to Cycle B conditions.

Between Cycles A and B, and Cycles C and D, the nuts were run back far enough to add additional lubricant, and the assembly was retorqued in the same five-step sequence as the previous cycle. This was done to simulate the installation procedure currently in use. A complete cleaning of the assembly was performed between Cycles B and C to simulate a maintenance event during the life of the component. During the maintenance event the stud is removed, cleaned and reinstalled. Therefore, Cycle D represents the typical coefficients of friction seen during the installation of a "used stud."

The torque wrenches and the Skidmore-Wilhelm torque-tension test units were calibrated prior to and at the completion of testing. The calibrations were factored directly into the equation used to calculate the coefficient of friction values. In addition to the initial calibration, the torque wrenches also received a daily calibration at the highest torque value expected during that day's tests. The accuracy of the torque wrenches was  $\pm 2$  percent.

### Phase II Testing

After the completion of the initial program described above and selection of Molykote P37 as the replacement lubricant, a follow-up program was designed to establish coefficient of friction ranges for additional fastener parameters. The test sequence was a simplified version of the Phase I testing and was defined as:

- Cycle 1      Representing a new, unused fastener torqued for the first time.  
(Run-In)
- Cycle 2      Representing a fastener having been subjected to a previous torquing cycle,  
(Design) disassembled, additional lubricant applied and retorqued. This generally  
represents actual fastener installation practice, and is considered most  
prototypical.
- Cycle 3      Representing a duplicate of the Cycle 2 loading step to increase the available  
(Design) data.

This simplified sequence was selected since the data from Cycles B and D in the initial phase were unaffected by Cycle C. This testing was designed to evaluate:

- ▶ additional fastener (stud and nut) material combinations
- ▶ different size fasteners - 3/4 to 2 inches in diameter
- ▶ different bearing (washer) materials
- ▶ different manufacturing methods - machined and rolled threads
- ▶ a new metallic-free lubricant as a potential alternate to Molykote P37

The additional fastener materials included K-500 studs with K-500 nuts, titanium (UNS R56401) studs with Alloy 625 nuts, Type 17-4PH (UNS S17400) studs with Type 316 (UNS S31600) stainless steel nuts. The detailed listing of materials, sizes and surface treatments are listed in Table 7. Except as noted in the following list, five duplicate assemblies were used for each lubricant tested. The following exceptions to the five assemblies were:

- ▶ Due to cost considerations, only one assembly was provided for testing of RLGMO, for the four machined Alloy 625 sets which ranged in size from 0.75, 1.75 and 2.0 inches in diameter.
- ▶ Four Type 17-4PH/Type 316 test assemblies used a Type 316 washer, while the fifth set was tested with a carbon steel washer to investigate the effect of the bearing material.
- ▶ Two K-500/K-500 assemblies were tested with each of the following washer materials for comparison to those tested with carbon steel washers: HY-80 (UNS J42015), Type 430 (UNS S43000) stainless steel, and Alloy 625.

### Anti-Seizing Testing

The high temperature anti-seizing test required exposing test assemblies, consisting of a stud with two nuts torqued to a load representing 2/3 of the yield strength of the stud material, to a temperature of 650°F. For each lubricant/material combination, one test assembly was removed

from the test oven at time intervals of one, three and six weeks. The final two test assemblies were removed after ten weeks. After each test assembly was removed from the oven, it was disassembled, inspected for the condition of the residual lubricant, cleaned and inspected for signs of material degradation, such as pitting or general corrosion. The installation and breakaway torque values were recorded for each cycle.

#### Anti-Galling Testing

For each material and lubricant combination, two test assemblies were subjected to up to twelve torquing and untorquing cycles. For each new test assembly, lubricant was applied to the stud and nut threads as well as the nut and washer bearing surfaces. After the fourth and eighth cycle the assembly was removed and cleaned of residual lubricant, reassembled and fresh lubricant was applied. For the first eight cycles, the assemblies were loaded to 2/3 of the minimum yield strength of the stud material. For the final four cycles, the assemblies were loaded to the minimum yield strength value. The installation and breakaway torque values were recorded for each cycle and any occurrence of galling was recorded. Because the assemblies were only relubricated after the fourth and eighth cycles, the probability of galling was enhanced. After the completion of the testing, each assembly was visually inspected at 15 to 20X magnification for evidence of galling. For each of the three alloy combinations, an initial test assembly was tested without lubricant to demonstrate that galling would occur.

#### Detrimental Material Evaluation

A sample of each candidate lubricant in its original container was evaluated for the following detrimental materials: mercury, antimony, bismuth, cadmium, lead, tin, zinc, sulfur, and phosphorus, and the following halides: chloride, bromide, and fluoride.

#### Health and Environmental Testing

Although details are beyond the scope of this paper, the following actions were taken for each candidate lubricant in order to assess the health and environmental issues:

- ▶ Off-gas testing was performed to determine if toxic gases would be released at 650°F.
- ▶ A hazardous material review was conducted in accordance with 40 CFR Part 261.
- ▶ A toxicological evaluation in accordance with the guidelines established by the International Agency for Research on Cancer (IARC), the American Conference of Governmental Industrial Hygienists (ACGIH) and the Environmental Protection Agency (EPA) was performed.

#### Corrosion Testing

The eight candidate replacement lubricants, MDSI, and RLGMO were applied to seven groups of representative fastener alloys, as listed in Table 2. The fastener assemblies were 3/4-10UNC studs and nuts.

**Table 2 Corrosion Test Alloy Combinations**

STUD MATERIAL	NUT MATERIAL
Steel, AISI 4140 Grade B7 (UNS G41400)	Steel ASTM A194, Grade 4
Type 304 Stainless steel (UNS S30400)	Type 304 Stainless steel
70/30 Copper Nickel (UNS C71500)	70/30 Copper Nickel (UNS C71500)
Nickel Aluminum Bronze (UNS C63200)	Nickel Aluminum Bronze (UNS C63200)
Monel K-500 (UNS N05500) QQ-N-286, Class A	Monel 400 (UNS N04400) QQ-N-281, Class A
Alloy 625 (UNS N06625) ASTM B446, Grade 1	Alloy 625 ASTM B446, Grade 1
Titanium (UNS R50400) ASTM B348, Grade 2	Titanium ASTM B348, Grade 2

The corrosion test program consisted of four categories of tests, which are summarized as follows:

#### Test 1 - Localized Fastener Corrosion Due To Lubricant In Air

In this test, studs and nuts of each fastener alloy were lubricated with one of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. The test specimens were placed in an oven with an air atmosphere at a temperature of  $250^{\circ}\text{F} \pm 10^{\circ}\text{F}$  and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than surfaces cleaned of lubricant.

#### Test 2 - Localized Fastener Corrosion Due To Lubricant In Salt Water

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Four nuts of the corresponding alloy were assembled on each lubricated stud to provide the test specimen. Some nut faces were coated with lubricant and some were cleaned of lubricant. The test specimen therefore contained lubricant filled crevices, lubricant covered noncreviced surfaces and clean noncreviced surfaces. Unlubricated control test specimens of each fastener alloy were also prepared. The test specimens were placed in a synthetic salt water test solution, heated to a temperature of  $175^{\circ}\text{F} \pm 5^{\circ}\text{F}$  and held for 750 hours. A separate test solution was used for each test specimen. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen of the same fastener alloy.

#### Test 3 - Environmentally Induced Corrosion Due To Lubricant In Salt Water Or In Distilled Water

In this test, studs and nuts of each fastener alloy were lubricated with each of the ten original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately  $650^{\circ}\text{F}$  for several hours to volatilize the lubricant. Two nuts of the corresponding alloy were assembled

on each stud. A spacer, fabricated from a nut of the corresponding alloy, was installed between the two nuts. The stud was then placed in a tensile test machine and loaded to 90 percent of the stud yield strength reported in the certified material test report. The two nuts were hand tightened against the spacer and the applied load was then released to provide the test specimen. Unlubricated control test specimens of each fastener alloy were also prepared.

For each lubricant and for each fastener alloy, sets of three test specimens were prepared consisting of one lubricated test specimen (as-lubricated), one test specimen made with lubricated and volatilized studs and nuts (volatilized), and one unlubricated test specimen (unlubricated). One set of test specimens was placed in a common synthetic salt water test solution, and one set of test specimens was placed in a common distilled water test solution. One unlubricated control test specimen for each fastener alloy was also tested in a separate salt water test solution and one in a separate distilled water test solution. The test solutions were heated to a minimum of 170°F and allowed to evaporate off water vapor so that the test solutions evaporated in approximately 150 hours.

The test specimens were then cleaned and examined visually and by fluorescent penetrant inspection to establish whether a test specimen in the set for any lubricant showed defects that were not found in the unlubricated control specimen of the same fastener alloy tested in the same medium. Studs were fluorescent-penetrant inspected prior to testing to identify defects that could interfere with the post-test inspection. Studs with defects were excluded from testing where possible.

#### Test 4 - Galvanically Assisted Localized Corrosion

In this test 3/4-10UNC studs of titanium alloy Grade 2 and carbon steel nuts were lubricated with each of the 10 original lubricants. Some of the lubricated studs and nuts were placed in an oven at approximately 650°F for several hours to volatilize the lubricant. One nut was assembled on each stud to provide the test specimen. Unlubricated control test specimens were also prepared.

In one series of tests, one test specimen for each lubricant and one unlubricated control test specimen was placed in an oven with an air atmosphere at a temperature of  $250^{\circ}\text{F} \pm 10^{\circ}\text{F}$  and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any surfaces covered by the lubricant were more heavily corroded than the unlubricated control specimens.

In a second series of tests, one lubricated test specimen and one test specimen made with lubricated and baked studs and nuts were placed in a distilled water test solution. One unlubricated control test specimen was also tested. A separate test solution was used for each test specimen.

The test solutions were heated to a temperature of  $175^{\circ}\text{F} \pm 5^{\circ}\text{F}$  and held for 750 hours. The test specimens were then cleaned and visually examined to establish whether any lubricated test specimen was more heavily corroded than the unlubricated control specimen.

## IV. Results And Discussion

### Coefficient of Friction Results

The coefficients of friction for each torque increment was calculated using the relationship shown in Appendix A. Various summary statistics were performed on the coefficient of friction data. A discussion of the statistics and the coefficient of friction results are included in Appendix B. These statistics were focused in five basic categories; the tolerance range of the data, form of the distribution of individual values, stud-to-stud variations, significant differences between run-in and design values and the significant differences between the design value and the used stud design value. The importance of the coefficient of friction on design is mainly the ability to accurately predict the stress in a loaded stud/fastener. A small range of the coefficient of friction is essential and is considered to be the best measure of the relative merit (from a coefficient of friction viewpoint) of lubricant candidates. A 90/95 tolerance interval (90 percent confidence that 95 percent of the data falls within the interval) was chosen to rank the lubricant candidates and the control lubricants.

The tolerance ranges for each lubricant/material combination have been calculated and are provided in Attachments I-IV of Appendix B. These are 90/95 tolerance ranges and the relative merit of each lubricant is shown in Figure 3 for the design and used stud design values of measured coefficient of friction. These results demonstrate that Molykote P37 is very similar in performance to RLGMO based on the mean coefficient of friction and the tolerance range.

### Phase I Test Results

The individual ranges for each lubricant are graphically presented in Figures 2 and 3 of Appendix B. Based on the evaluation of the test data, Molykote P37 can be used in place of RLGMO or MDSI with no adjustment to the specified torque values determined for RLGMO and MDSI, because of the similarity in coefficient of friction range. The overall 90/95 tolerance ranges of coefficient of friction, inclusive of the four material combinations tested, for the replacement and the control lubricants are listed in Table 3.

Table 3      Coefficient of Friction Ranges (90/95 Tolerance Interval)

LUBRICANT	COEFFICIENT OF FRICTION RANGE	
	Westinghouse Testing	Established Range
Dow Corning Molykote P37 Paste	0.06 - 0.16	-----
RLGMO	0.06 - 0.15	0.05 - 0.11
MDSI	0.05 - 0.26	0.05 - 0.14

Although the ranges for the replacement lubricants appear to be significantly larger than the established range listed for RLGMO, the results of the Westinghouse testing actually produced a RLGMO range of 0.06 to 0.15 which is comparable to the range for Molykote P37. The range for MDSI is significantly wider than the replacement. The basis for the difference between the Westinghouse results and the established range is that Westinghouse data have been skewed to the high end by the inclusion of unplated Alloy 625 fasteners in the testing. The previously

established ranges for coefficient of friction were based on test data from a limited number of alloys, primarily alloy steels. Nickel-chromium-iron based alloy fasteners were not included in previous testing. Using the data of Tables XI and XIII of Appendix B, the ranges listed in Table 4 have been calculated without Alloy 625 data included.

**Table 4 Coefficient of Friction Range (excluding Alloy 625)**

LUBRICANT	COEFFICIENT OF FRICTION RANGE (excluding Alloy 625)	
	Westinghouse Testing	Established Range
Dow Corning Molykote P37 Paste	0.07 - 0.12	----
RLGMO	0.06 - 0.13	0.05 - 0.11
MDSI	0.05 - 0.13	0.05 - 0.14

Several conclusions can be drawn from these data. First, the coefficient of friction ranges for RLGMO and Molykote P37 continue to be consistent with each other, having the same arithmetic average, and the Molykote P37 range is within the MDSI range. Second, the RLGMO and MDSI ranges found in the Westinghouse testing match well with the established ranges when unplated Alloy 625 fasteners are excluded. Finally, it is technically feasible to develop separate coefficient of friction ranges for unplated Alloy 625, which can allow for tighter control on design torques. Based on the test results and the comparison to the currently acceptable ranges, two coefficient of friction ranges for Molykote P37 were established. The standard range, 0.07 - 0.12, will be that which excludes the Alloy 625 results, since this range is directly comparable to the current ranges used for RLGMO and MDSI. It should be noted that this range has been developed using 3/4-inch fasteners of uncoated and phosphate coated alloy steel, alloy steel nuts, and steel washers, as well as Monel K-500 studs with Monel 400 nuts and steel washers. The vast majority of fasteners in service are either alloy steel or Monel K-500, both of which have been included in the Westinghouse testing. The Phase II testing was initiated to evaluate other fastener materials against these ranges. In addition, a second range was established that is specific to unplated nickel-chromium-iron-based alloy fasteners based on the Alloy 625 test data. This range of coefficient of friction is 0.06 - 0.16 for Molykote P37.

#### Phase II Test Results

As with the coefficient of friction data generated in the original (Phase I) program, various summary statistics were performed on the data. These statistics included the tolerance range of the data, significant differences between run-in (Cycle 1) and design values (Cycle 2) and the significant differences between the design value and the used stud design value (Cycle 3). The actual coefficient of friction results for all Phase II tests are provided in Appendix C. A summary of the mean, standard deviation and 90/95 tolerance range of the coefficient of friction results for Molykote P37 and RLGMO is provided in Table 5 for the run-in cycle and Table 6 for the design cycles, that is, combined coefficient of friction values for Cycles B and D for Phase I and Cycles 2 and 3 for Phase II. For alloy combinations that included less than four test assemblies, only the mean and standard deviation is reported. The data in Tables 5 and 6 are grouped by the composition of the test stud. The results reported in Tables 5 and 6 are considered worst case, that is, skewed to the high side of the coefficient of friction range, since the fasteners have been procured as off-the-shelf items. The only exception to this are the four sets of Alloy 625

assemblies, beginning with the label 'IM' and the alloy steel assemblies labeled 'AS', which are actual production hardware.

Comparison of the design (Cycle 2) coefficient of friction values from the Phase II tests supports the substitution of Molykote P37 for RLGMO. This is especially true for the alloy steel and Alloy 625 materials. The most significant difference between Molykote P37 and RLGMO is observed for the largest diameter fasteners. For sizes up to 1.75 inches in diameter the difference between the Molykote P37 and RLGMO coefficients of friction is less than or equal to 0.02; however, for the 2.0 inch Alloy 625 fastener combination the mean coefficient of friction for Molykote P37 exceeds that of RLGMO by more than 0.05 for the run-in cycle and 0.02 for the subsequent cycles. For fastener sizes larger than 1.5 inches, which rely on torque to establish the preload, the use of a run-in cycle and prototypic testing should be strongly considered.

The other instance in which a significant difference between lubricants was observed occurred for the Type 17-4PH stud with a Type 316 nut bearing on a Type 316 stainless steel washer. For this material combination the coefficient of friction range more closely matched that originally established for Alloy 625 fasteners. When a carbon steel washer was substituted for the stainless steel washer the coefficient of friction values began to converge.

The following summarizes the results observed for each alloy family tested and for the various fastener parameters evaluated:

<b>Alloy Steel</b>	The coefficient of friction data for all alloy steel combinations were essentially the same and within the range of the previous testing. The only exception is for Molykote P37 on the larger, 1.5-inch diameter fasteners, which exhibited a Cycle 2 mean coefficient of friction of 0.12 and a tolerance range of 0.10 to 0.14. This is compared to an equivalent range of 0.10 to 0.12 for the RLGMO. It should be noted that for the run-in cycle the mean and tolerance range for both lubricants are essentially the same. Examination of the data indicates that for Cycles 1 through 3 as well as for each load increment, the coefficients of friction for RLGMO are essentially the same while for Molykote P37 the values for Cycles 2 and 3 increase slightly. This observation is contrary to the general trend that the coefficient of friction tends to decrease with subsequent cycles.
<b>Monel K-500</b>	As observed in the original testing, Molykote P37 consistently exhibits a mean coefficient of friction as well as a tolerance range which was approximately 0.01 to 0.02 higher than that of RLGMO. However, in the Phase II testing the absolute value of the coefficient of friction results for both lubricants is shifted slightly higher than in the original testing, producing 90/95 confidence range up to 0.134 (K-500/K-500/Carbon Steel) for Molykote P37 on the 0.75-inch fasteners and a range up to 0.144 (K-500/Monel 400/Carbon Steel) on the larger 1.5-inch fastener. Although close examination of the large diameter fastener results (see Appendix C, Data Sets 61-65 and 156-160) indicate that the ranges for both lubricants are skewed higher due to the final torque increment which exhibits a large non-linear increase in coefficient of friction possibly due to the lower strength of the Monel 400 nut. Reanalyzing the data excluding the highest load increment reduces the maximum of the Molykote P37 range to 0.135, which is consistent with the other K-500 data.
<b>Type 17-4PH</b>	As mentioned above, a significant difference was observed between the lubricants when a Type 316 stainless steel washer was employed. The Molykote P37 exhibited a significant decrease in coefficient of friction from the high Cycle 1 results to Cycle 2 results for the four assemblies using the Type

316 washer, but no difference on the one assembly which used a carbon steel washer, since the coefficient of friction for Cycle 1 and Cycle 2 were low. Therefore, it appears that the interaction between the Type 316 nut and washer results in a significant increase in the initial coefficient of friction for the Molykote P37 while the RLGMO was better at mitigating this effect. Since austenitic stainless alloys are known to be prone to galling, the higher coefficient of friction was not surprising. These types of material combinations should be evaluated using ranges similar to that previously discussed for unplated Alloy 625.

<b>Alloy 625</b>	The Alloy 625 assemblies produced mixed results. The additional set of commercially procured fasteners with Alloy 625 washers (Alloy Code II) duplicates the results of the original test program producing coefficients of friction consistent with the previous range. The use of chromium plating, as expected provides a significant reduction in the coefficient of friction. However, the two 0.75-inch fasteners, IMC2 and IMC3, which are actual production hardware, result in a low coefficient of friction range comparable to any of the alloy steel assemblies. As the fastener size increases to 1.75 inches and ultimately 2.0 inches, the Molykote P37 coefficient of friction diverges from that of the RLGMO. Also, eventually in the 2.0-inch size, the Molykote P37 friction exceeds the previous range recommended for Alloy 625. A possible explanation for the lower coefficient of friction for the 0.75-inch fasteners is the use of the heavy hex nuts with the larger diameter bearing face. Examination of the 'IM' nuts and washers indicated that the actual bearing area was significantly larger with the heavy hex nuts than with the smaller commercial nuts. For the same load, this would have resulted in a lower bearing stress and lower tendency for galling. However, as the fastener size increased, even the larger nuts and bearing area did not help maintain a reasonable coefficient of friction range for the Molykote P37. As discussed in the <b>Surface Coating</b> paragraph below, the use of coating such a chromium plating may reduce the coefficient of friction on the larger fastener sizes.
<b>Titanium</b>	For the titanium combination tested, both Molykote P37 and RLGMO exhibited essentially identical coefficient of friction ranges. The tolerance ranges for both lubricants extend up to coefficients of 0.14. Although neither lubricant exhibits any significant difference from Cycles 1 through 3, they both exhibit increasing coefficients of friction at the higher load increments, suggesting that an additional interaction is occurring between the materials at higher loads.
<b>Size Effects</b>	The Molykote P37 appears to be more sensitive to size effects above 1.5 inches in diameter than RLGMO. Up to this size both lubricants exhibited a slight increase in the coefficient of friction values at approximately the same rate; however, for the 2.0-inch Alloy 625 fasteners the Molykote P37 coefficient of friction significantly exceeds that of RLGMO, resulting a Cycle 1 mean value as high as 0.176 compared to 0.117 for RLGMO. For this size fastener the required load may be resulting in a breakdown of the Molykote P37's ability to properly perform, although it is noted that an improvement was observed for Cycles 2 and 3.
<b>Run-in Cycles</b>	For most alloy combinations tested a significant decrease in the coefficient of friction values was observed between Cycle 1 and Cycle 2, indicating that a run-in cycle or pretorquing step is valuable in controlling the final coefficient of friction value. This difference was least noticeable for the alloy steel combinations, the chromium plated Alloy 625 assemblies and for the 0.75-inch

unplated Alloy 625 fasteners with the heavy hex nuts. The plating helps to reduce the tendency to gall for susceptible materials during the first torque cycle.

<b>Washer Materials</b>	The effect of washer (bearing) material was most significant when materials which are known to be prone to galling were used, such as previously discussed for the Type 17-4 PH assemblies. Higher coefficients of friction were noted for the alloy steel assemblies which used a Type 430 stainless steel lock plate. Changing washer materials in conjunction with the K-500 studs did not produce any significant differences or trends. Likewise, no significant difference was observed by changing from carbon steel washers to Alloy 625 washers for the Alloy 625 assemblies.
<b>Surface Coating</b>	Surface coating provides a significant benefit in both decreasing the coefficient of friction range as well as narrowing the standard deviation of the data compared to the equivalent materials in the uncoated condition. The three types of surface treatments tested were: manganese phosphate coating and zinc plating on alloy steel, and chromium plating on Alloy 625.
<b>Class of Fastener Fit</b>	No significant difference was observed between Class 2 (Alloy Code IMC2) and Class 3 (IMC3) Alloy 625 fasteners tested, implying that the tighter thread tolerances for the Class 3 fit does not have an influence on the coefficient of friction value.
<b>Manufacturing Method</b>	No significant difference was observed between machine and rolled threads.
<b>Potential Alternate Lubricant</b>	Limited testing (six different fastener assemblies) was performed with the new metallic-free lubricant, labeled as N7000. The results of the testing with N7000 are provided at the end of Appendix C. In general, this lubricant produced coefficient of friction values which exceed those of Molykote P37 by approximately 0.01 for all three torque cycles.

One obvious exception was the original Alloy 625 combination (Alloy Code I) in which the N7000 values were significantly less than either Molykote P37 or RLGMO. This result was so far out of line with the other data that the test laboratory was requested to repeat the test with a single spare Alloy 625 fastener assembly. This repeat test produced a result which was more expected. Although no explanation as to the source of the low values is offered, the retest values are considered more representative based on the other assemblies tested.

Based on the results of the limited screening testing, N7000 would not have been selected over Molykote P37 if it had been included in the original test matrix.

#### Use of the Coefficient of Friction Data

The tolerance ranges provided in Appendices B and C include data over a wide range of loading conditions, that is, up to 2/3 of the yield strength of the stud material. In many applications, applied loads will be significantly less than this limit. For some of the alloys tested the coefficient of friction increases with increasing load; therefore, the raw data should be consulted to get a more representative indication of coefficient of friction for the range of load in question.

**Table 5 Run-in Coefficient of Friction Values**

STUD MATERIAL	ALLOY CODE (Note 1)	LUBRICANT					
		Molykote P37			RLGMO		
		Mean	Std. Dev.	90/95 Tolerance	Mean	Std. Dev.	90/95 Tolerance
Alloy Steel	A	0.097	0.007	0.076 - 0.118	0.092	0.003	0.083 - 0.101
	AM	0.099	0.010	0.075 - 0.122	0.097	0.005	0.084 - 0.110
	P	0.088	0.004	0.078 - 0.098	0.089	0.008	0.069 - 0.109
	AR1	0.111	0.010	0.086 - 0.135	0.117	0.005	0.103 - 0.130
	AZ	0.086	0.005	0.074 - 0.098	0.097	0.009	0.074 - 0.119
	AS	0.095	0.016	0.053 - 0.137	0.091	0.024	0.027 - 0.155
K-500	M	0.102	0.008	0.082 - 0.122	0.088	0.009	0.066 - 0.110
	MK	0.125	0.009	0.101 - 0.147	0.105	0.007	0.087 - 0.123
	MCU	0.131	0.014	0.090 - 0.171	0.126	0.009	
	MH	0.147	0.006		0.139	0.006	
	MS	0.141	0.011		0.124	0.009	
	MI	0.141	0.010		0.122	0.007	
	MA	0.140	0.014	0.105 - 0.175	0.108	0.013	0.075 - 0.140
	MA (Note 2)	0.135	0.010	0.110 - 0.160	0.103	0.009	0.079 - 0.127
Alloy 625	I	0.164	0.021	0.112 - 0.216	0.164	0.025	0.102 - 0.226
	ICR	0.105	0.011	0.079 - 0.131	0.104	0.007	0.088 - 0.121
	II	0.149	0.015	0.113 - 0.185	0.160	0.015	0.122 - 0.197
	IMC2	0.111	0.010	0.087 - 0.135	0.102	0.015	
	IMC3	0.101	0.008	0.082 - 0.120	0.109	0.006	
	IMA	0.122	0.020	0.070 - 0.174	0.093	0.016	
	IMB	0.176	0.040	0.066 - 0.285	0.117	0.014	
Titanium	T	0.117	0.009	0.094 - 0.139	0.115	0.010	0.091 - 0.139
Type 17-4PH	SS	0.163	0.015	0.125 - 0.202	0.130	0.010	0.103 - 0.156
	SSC	0.112	0.010		0.115	0.002	
<b>Notes:</b> (1) See the Key to the Alloy Codes located in Table 7. (2) Same as MA, excluding the highest torque increment.							

**Table 6 Design Coefficient of Friction Values**

STUD MATERIAL	ALLOY CODE (Note 1)	LUBRICANT					
		Molykote P37			RLGMO		
		Mean	Std. Dev.	90/95 Tolerance	Mean	Std. Dev.	90/95 Tolerance
Alloy Steel	A	0.097	0.005	0.082 - 0.112	0.088	0.004	0.076 - 0.100
	AM	0.103	0.009	0.081 - 0.125	0.090	0.007	0.072 - 0.108
	P	0.090	0.005	0.078 - 0.102	0.083	0.005	0.071 - 0.095
	AR1	0.121	0.011	0.094 - 0.149	0.111	0.005	0.099 - 0.123
	AZ	0.081	0.007	0.063 - 0.100	0.082	0.010	0.058 - 0.106
	AS	0.080	0.015	0.041 - 0.120	0.079	0.014	0.041 - 0.116
K-500	M	0.094	0.008	0.074 - 0.114	0.075	0.006	0.060 - 0.090
	MK	0.115	0.008	0.096 - 0.134	0.095	0.008	0.077 - 0.114
	MCU	0.097	0.011	0.069 - 0.125	0.100	0.011	
	MH	0.119	0.009		0.105	0.010	
	MS	0.105	0.014		0.097	0.007	
	MI	0.112	0.007		0.112	0.007	
	MA	0.120	0.010	0.095 - 0.144	0.106	0.009	0.085 - 0.127
	MA (Note 2)	0.117	0.007	0.098 - 0.135	0.102	0.008	0.080 - 0.123
Alloy 625	I	0.108	0.010	0.083 - 0.133	0.113	0.014	0.078 - 0.148
	ICR	0.100	0.012	0.070 - 0.130	0.094	0.013	0.062 - 0.126
	II	0.111	0.009	0.088 - 0.134	0.118	0.012	0.089 - 0.148
	IMC2	0.089	0.010	0.065 - 0.113	0.101	0.006	
	IMC3	0.087	0.008	0.067 - 0.106	0.104	0.006	
	IMA	0.108	0.017	0.063 - 0.152	0.099	0.012	
	IMB	0.129	0.028	0.051 - 0.207	0.106	0.014	
Titanium	T	0.113	0.014	0.078 - 0.149	0.107	0.014	0.073 - 0.141
Type 17-4PH	SS	0.121	0.015	0.082 - 0.160	0.098	0.012	0.066 - 0.130
	SSC	0.110	0.006		0.083	0.007	

**Notes:**

(1) See the Key to the Alloy Codes located in Table 7.  
(2) Same as MA, excluding the highest torque increment.

**Table 7 Key to Tables 5 and 6**

ALLOY CODE	ALLOY COMBINATION			COMMENTS
	Stud	Nut	Washer	
A	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AM	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Machined threads
P	AISI 4140, Mn Phosphate Coated	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AR1	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	1.5 inches
AZ	Steel, Grade 5, Zinc plated	Carbon Steel, Grade 5	Carbon Steel	Rolled threads
AS	AISI 4340	AISI 4340	Type 430 Stainless Nutlock	Machined threads 1.0 inches
M	K-500	Monel 400	Carbon Steel	Rolled threads
MK	K-500	K-500	Carbon Steel	Rolled threads
MCU	K-500	K-500	70-30 Cu-Ni	Rolled threads
MH	K-500	K-500	HY 80	Rolled threads
MS	K-500	K-500	Type 430	Rolled threads
MI	K-500	K-500	Alloy 625	Rolled threads
MA	K-500	Monel 400	Carbon Steel	Rolled threads 1.5 inches
I	Alloy 625	Alloy 625	Carbon Steel	Rolled threads
ICR	Alloy 625, Chromium plated	Alloy 625	Carbon Steel	Rolled threads
II	Alloy 625	Alloy 625	Alloy 625	Rolled threads
IMC2	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 2
IMC3	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 3
IMA	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 1.75 inches
IMB	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 2.00 inches
T	Titanium, Gr 5	Alloy 625	Carbon Steel	Rolled threads
SS	Type 17-4PH Stainless Steel	Type 316 stainless	Type 316 stainless	Rolled threads
SSC	Type 17-4PH Stainless Steel	Type 316 stainless	Carbon Steel	Rolled threads

### Anti-Seizing Test Results

To begin this test a coefficient of friction value of 0.10 was assumed in order to develop torque values with which to load the test assemblies. Each test assembly was given one run-in cycle to the calculated torque value, disassembled, cleaned, relubricated and retorqued prior to placing in an oven at 650°F. Based on the coefficient of friction testing results, the assumed coefficient of friction of 0.10 was within the range for all lubricants except NIKAL, Neolube No. 650 and NM-91. For NIKAL and NM-91, the coefficient of friction of 0.10 is below the determined coefficient of friction range, resulting in lower loads on these studs than the test assemblies for the other lubricants. However, both of these lubricants required high breakaway torques, indicating that their actual performance would have been even worse had higher loads (torques) been used. For Neolube No. 650 a coefficient of friction of 0.10 was actually above the determined range, indicating higher loads were applied to these assemblies than to the others.

The tabulated breakaway torque results for the anti-galling test are shown in Tables 1 through 3 in Appendix D. After one week of exposure approximately half of the 30 test assemblies still exhibited evidence of moisture after the assembly was untorqued and examined. Except for one test assembly, after three weeks of exposure, the lubricant on test assemblies had completely dried. That is, the oil constituent had oxidized, leaving only the solid anti-seizing additives. After six weeks of exposure the test assemblies had completely dried lubricant. Once dried, all of the candidate lubricants were easily removed with a nylon brush as they formed a dry powder or dust. The fasteners which had moist lubricant present could be cleaned with a cloth, but it took more time because residual lubricant smeared. Only those assemblies coated with RLGMO or MDSI required wire brushing to remove the dried baked on lubricant. Even after wire brushing, visual evidence of RLGMO was still present on the six-week assemblies.

Based on the 6- and 10-week anti-seize test results, Molykote P37 exhibited the best performance of any candidate lubricant. For both the alloy steel and K-500/Monel 400 fastener combinations, the breakaway torques for Molykote P37 were less than 40 percent higher than the installation value. For the stainless steel fasteners the breakaway torque is approximately 2.5 times the installation value. This material combination, that is, unplated stainless steel studs and nuts, is considered a worst case. For RLGMO the breakaway torques on alloy steel and K-500/Monel 400 were the same as for Molykote P37. On the unplated stainless steel fasteners, the RLGMO breakaway torques were only 60 percent higher than installation values, indicating a noticeable difference between the two lubricants. Breakaway torques for MDSI were lower than either the Molykote P37 or RLGMO, although during the untorquing audible clicking accompanied by jumping of the torque wrench follower occurred in all of the MDSI assemblies raising a question as to the precise torque values reported. Somewhat higher breakaway torque values are, therefore, expected if MDSI is replaced with Molykote P37.

### Anti-Galling Test Results

Tables 1 through 6 of Appendix E provide the raw data for the anti-galling test. For each alloy an initial test assembly was tested without lubricant and in each case galling or seizing occurred within the first four cycles, confirming that the material combinations without lubrication will gall. In general, all lubricant/material combinations, except Never Seez and MDSI, completed the first eight cycles with no signs of galling. On the K-500/Monel 400 and stainless steel assemblies, the Never Seez showed signs of galling by the second cycle via audible clicking accompanying erratic jumps on the load cell gage. The clicking and uneven loading increased in frequency on each subsequent cycle until the testing was stopped after four cycles on the K-500/Monel 400 assemblies and six and seven cycles on the two stainless steel assemblies. The MDSI lubricated K-500/Monel 400 and alloy steel assemblies showed erratic increases in the installation torque values during the first eight cycles. Galling was visually observed on the

threads during the cleaning step between Cycles 8 and 9.

In general, all lubricants required the highest torque value on Cycle 1, which then decreased to a relatively stable value through Cycle 8. For some lubricants, primarily NM-91 and N2000, a small increase in torque was seen on Cycle 5, which represented the reapplication of fresh lubricant on a cleaned, although previously used assembly. The higher values observed on Cycle 1 and occasionally at Cycle 5 represent the run-in cycle for the lubricant on a clean surface. It has been established by previous testing that during the initial loading of a new fastener a higher coefficient of friction exists compared to subsequent loading cycles for the same fastener assembly. This is seen clearly in the coefficient of friction results. As long as the torque values remained relatively constant or decreased between Cycles 2 and 8 galling was not suspected. With the exception of the small increase on Cycle 5 mentioned above, except NIKAL and MDSI, the lubricants completed eight cycles without galling.

To provide a more severe test of the lubricants ability to prevent galling, the load was increased to the stud material's yield strength during the last four cycles. As seen in the data of Appendix E, when the load was increased to the yield strength, most fasteners required a higher torque value on Cycle 9, which generally decreased during the final three cycles. Again this represents a run-in cycle for the higher loading. During Cycle 9 audible clicking and exceptionally high torques were noted for one of the two stainless steel test assemblies lubricated with each of the following lubricants: N5000, Neolube No. 650, Never Seez, Molykote P37 and MDSI. (Note: Testing of the assemblies lubricated with NIKAL had been discontinued prior to Cycle 9 due to severe galling.) On Cycle 10 the torque values for all of these assemblies decreased and remained stable through Cycle 12. These lubricants exhibited slightly more visible evidence of galling on the stainless steel assemblies than the remaining four lubricants: N1000, N2000, NM-91 and RLGMO. Since this event was only seen on the stainless steel assemblies at the load equal to the yield strength and torques for subsequent cycles returned to more expected values, these results are not considered significant because of the limited usage of austenitic stainless steel fasteners. In addition, Cycles 9 through 12 represent a severe over-test because fasteners in service are not intentionally preloaded to yield strength.

#### Detrimental Material Evaluation

Five of the eight candidates completely met the detrimental material limits, while two of the remaining three exceeded the limit for one element by less than 10 ppm. The final lubricant (NM-91) contained almost 700 ppm of sulfur.

#### Health and Environmental Evaluation

The MSDS for the eight candidate lubricants were reviewed for potential generation of hazardous wastes. The review indicated that none of the candidate lubricants contain hazardous substances per the Code of Federal Regulations, Title 40, Part 261; therefore, the use of any of these lubricants would not lead to the generation of a hazardous wastes based on their composition or physical/chemical characteristics and all are equally acceptable from a disposal standpoint.

Off-gas testing of each candidate lubricant was performed to determine the composition of volatile products produced during a 48 hour exposure at 650°F. Molykote P37, Neolube No. 650 and NM-91 off gassed formaldehyde, which is a suspected human carcinogen as classified by ACGIH. The sources of formaldehyde in Molykote P37 are mineral oil and polyisobutylene, which are essential ingredients in the formulation. It would not be feasible to eliminate the sources of formaldehyde. However, formaldehyde would not be released at temperatures below about 600°F. For all candidate lubricants, the organic constituents off-gas during the first 24 hours of

heating indicating that the first 24 hours is the period of greatest concern. The recommended safety practices to be followed when using Molykote P37 are as follows:

- ▶ use chemical worker goggles
- ▶ use neoprene or equivalent gloves
- ▶ avoid of extreme heat, such as during welding, and motorized methods to remove the residual lubricant, such as wire brushing
- ▶ use adequate ventilation during the first 24 hours of high temperature operations
- ▶ wipe off excess lubricant before hot operations

Independently, a certified industrial hygienist reviewed the MSDS for the candidate lubricants for human toxicological concerns. The results are summarized as follows:

- ▶ nickel and nickel compounds are known human carcinogens (Group 1 Carcinogens by the IARC)
- ▶ copper and nickel produce chronic toxic metal effects in humans, although copper is less of a human toxicological problem than nickel

Molykote P37 does not contain nickel or copper, and thus is not a human toxicological concern.

#### Corrosion Testing Results

No corrosion effects were observed in any fastener specimen lubricated with Molykote P37. Corrosion effects were observed with several of the other candidate replacement lubricants. The following summarizes the results of the corrosion testing:

- ▶ None of the eight candidate replacement lubricants, including Molykote P37, caused any corrosion effects in air which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.
- ▶ N1000, Never Seez and NM-91 caused localized corrosion, that is, pitting and crevice corrosion, of K-500 fasteners which was more apparent than that occurring in unlubricated K-500 fasteners under similar conditions of salt water exposure.
- ▶ N1000 intergranularly attacked Type 304 stainless steel fasteners in salt water exposure.
- ▶ None of the eight candidate replacement lubricants for RLGMO caused any galvanically assisted localized corrosion effects in air or distilled water. These corrosion effects which are different from or more apparent than that caused by RLGMO, MDSI or from corrosion effects under similar conditions of exposure to unlubricated fasteners in any of the tested materials.

## V. Conclusions

Based on the results of the initial testing, Westinghouse concluded that Dow Corning Molykote P37 is the best replacement for RLGMO in that it best simulates the coefficient of friction range, the anti-galling and anti-seizing properties of the RLGMO, is non-hazardous, poses minimal health risks and is non-corrosive to the fastener alloys evaluated. Initial testing also indicated that Molykote P37 could be used as a replacement for MDSI based on the improved coefficient of friction range. However, because MDSI is not hazardous and does possess the best anti-seizing resistance of any lubricant tested, an across the board replacement was not undertaken.

Additional testing performed in a Phase II program confirmed the choice of Molykote P37 and greatly expanded the coefficient of friction database to additional fastener alloy combinations. Dow Corning Molykote P37 Paste meets the requirements of Commercial Item Description, A-A-59004, "Anti-Galling Compound, Thread Lubricating, Seizing Resistant, and Calcium Hydroxide Containing".

The selection of Molykote P37 by Westinghouse does not reflect functional deficiencies with the other candidate lubricants in this evaluation but rather that Molykote P37 was the best match for RLGMO based on the Westinghouse criteria. Readers should compare the results discussed herein against the specific application requirements prior to selection of a lubricant.

## VI. Acknowledgments

The authors wish to acknowledge N.P. Grado for designing and coordinating the corrosion testing, L.N. Eaton for assisting in the evaluation of the coefficients of friction, K.M. Goellner and R.D. Hays of the Westinghouse Bettis Laboratory for performing the toxicological evaluations, R. Hagar of the Naval Sea Systems Command for coordinating the environmental off gas testing and E.E. Toomey for assistance in procuring the test material and expediting the placement of the testing contracts. The authors also acknowledge the contributions of S.W. Bodner of the Naval Sea Systems Command for his sponsorship and continued interest in this work.

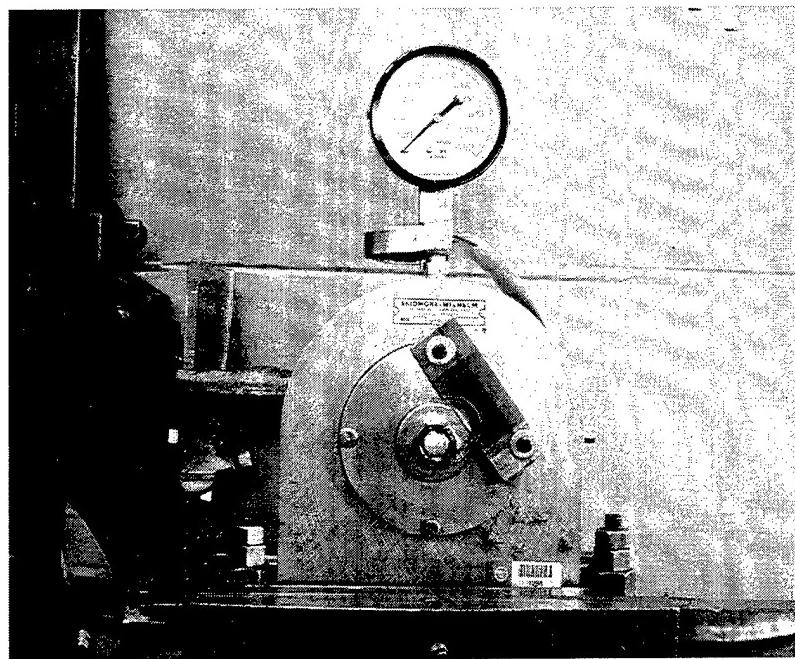


Figure 1. Skidmore-Wilhelm Torque Tension Unit, Model RL

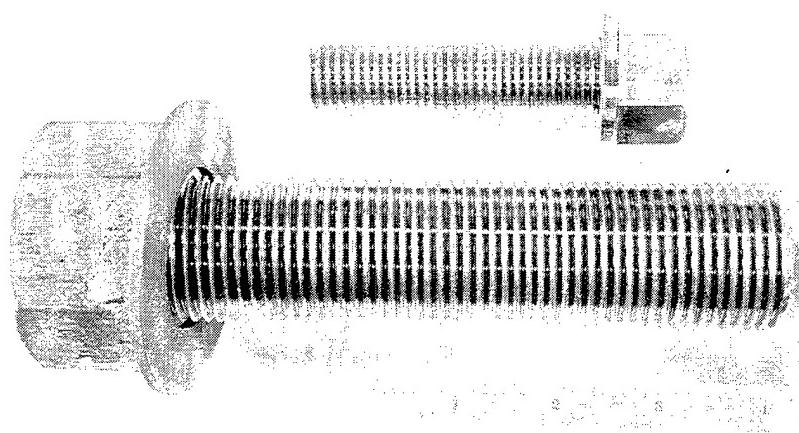


Figure 2. Typical Fastener Assemblies: 1.5-8UNC-2A Monel K-500 (Alloy Code MA) and 0.75-10UNC-3A Alloy 625 (Alloy Code IMC3)

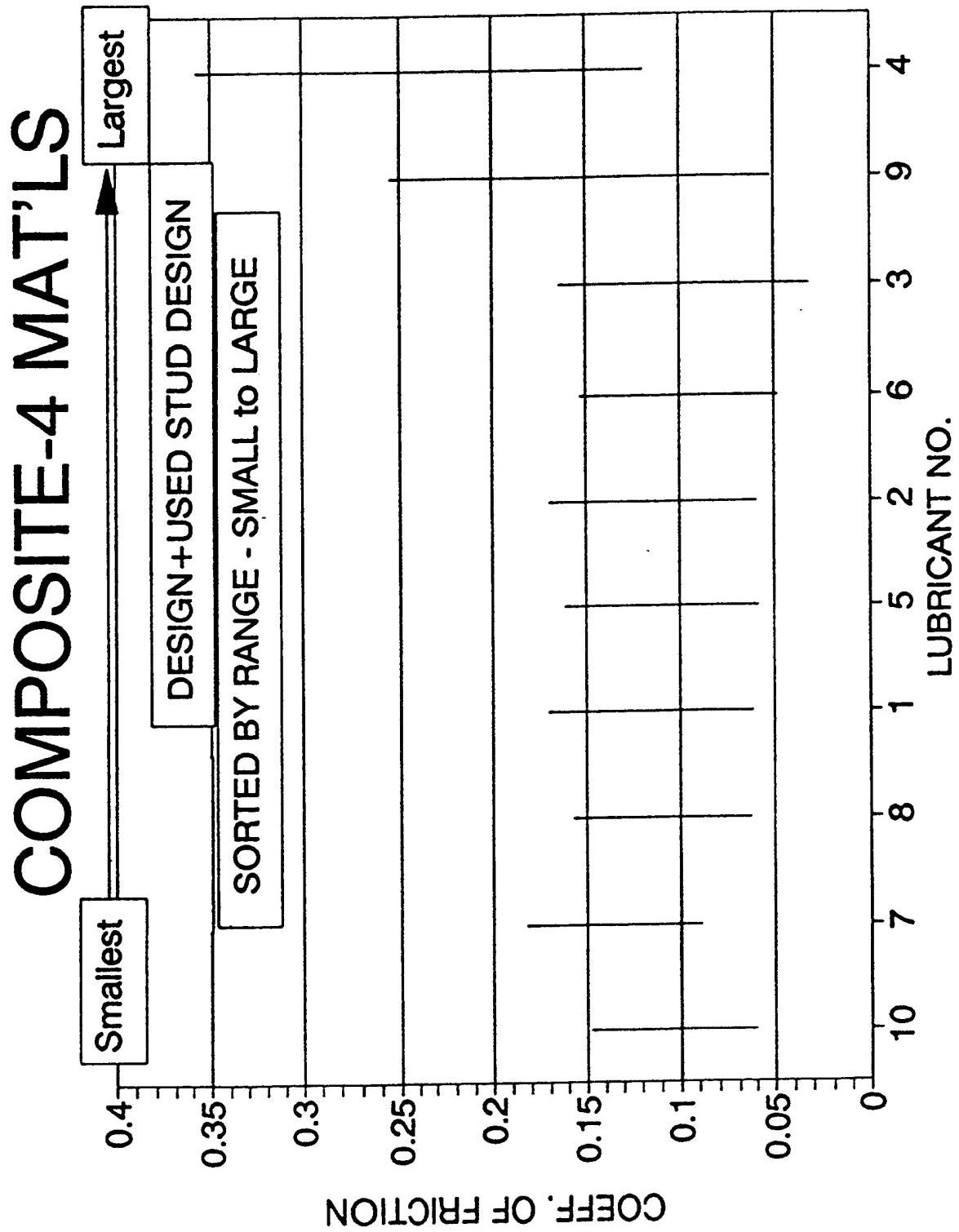


Figure 3. Coefficient of Friction Ranges of the Phase I Lubricants

## Appendix A

### EQUATION FOR CALCULATING THE COEFFICIENT OF FRICTION ( $\mu$ )

$$\mu = - \left[ \frac{C + \sqrt{C^2 - 4D_b A \sin \lambda}}{2 D_b \sin \lambda} \right]$$

where:

$$C = - \left[ D_b \cos \alpha_n \cos \lambda + \frac{24T}{P} \sin \lambda + E \cos \lambda \right]$$

$$A = \left[ \frac{24T}{P} \cos \alpha_n \cos \lambda - E \cos \alpha_n \sin \lambda \right]$$

T = Torque, ft-lb.

P = Axial load, lb.

E = Minimum pitch diameter, in.

D<sub>b</sub> = Flats diameter of nuts, in.

B = Diameter of hole in washer, in.

$$D_b = \frac{2}{3} \frac{D_h^3 - B^3}{D_h^2 - B^2}$$

N = Number of threads per inch

$\alpha$  = One-half the thread profile angle

$$\lambda = \text{Helix angle} = \arctan \frac{1}{N E \pi}$$

$$\alpha_n = \arctan (\tan \alpha \cos \lambda)$$

## Appendix B

### SUMMARY STATISTICS OF COEFFICIENT OF FRICTION DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD AND GRAPHITE IN MINERAL OIL (RLGMO)

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e., the individual loads and corresponding torque values, and the detailed statistical analysis can be obtained by requesting from the authors at:

Westinghouse Electric Company  
Plant Apparatus Division  
500 Penn Center Boulevard  
Pittsburgh, PA 15235-5713

**SUMMARY STATISTICS OF COEFFICIENT OF FRICTION  
DATABASE OF REPLACEMENT CANDIDATES FOR RED LEAD  
AND GRAPHITE IN MINERAL OIL (RLGMO)**

**I. PURPOSE**

The purpose of this enclosure is to provide the analysis (summary statistics) of the torque-tension test results of coefficient of friction data of lubricant replacement candidates for red lead and graphite in mineral oil (RLGMO).

**II. BACKGROUND**

The final approved coefficient of friction testing matrix for RLGMO replacement lubricant candidates includes ten lubricants and four (4) material combinations. This is an incomplete blocked experiment with only minor perturbations\* from a complete blocked experiment. Forty sets of torque-tension tests were performed. The data from these tests are used to establish the coefficient of friction for each lubricant/material combination. There are five (5) studs per combination<sup>†</sup> and four loading sequences. Each loading sequence contains six (6) values of coefficient of friction; five (5) on the loading portion with the highest load equal to 2/3 yield strength and one (1) break-away value<sup>‡</sup>.

\* For the Alloy Steel (B7) Stud/Nut fasteners, only two (2) studs were tested.

\*\* Breakaway coefficient of friction not provided in this enclosure.

**III. DESCRIPTION OF SUMMARY ANALYSIS**

**A. Summary Statistics**

The analysis of the torque-tension coefficient of friction testing focused on summary statistics for each of the 40 dataset combinations. Main features include an overall assessment of the variation of the coefficient of friction, mean values, standard deviations and the range of the data.

Most of the coefficient of friction distributions can be characterized by a normal distribution with a smaller standard deviation for the lower half than the upper half of the distribution.

**B. Stud and Load Sequence Subgrouping**

The data are grouped by material and provided in tables of the attachments (one material combination in each attachment) to this enclosure. A mean value and standard deviation were calculated for each stud loading portion of the test. In addition, mean values and standard deviations were calculated for each of the four (4) loading sequences which include all five (5) studs.

The categories of the 4-step loading sequences are defined as:

1. run-in,
2. design,
3. used stud run-in, and
4. used stud design.

The initial run-in represents a new stud cleaned and lubricated, and then torqued. The stud is unloaded, lubricated and loaded again as in the field application. This represents the design values of coefficient of friction. The stud is unloaded, cleaned and lubricated and loaded again. This represents a used stud run-in. The stud is unloaded, lubricated, and loaded again, representing the design case for a used stud. A test of significant differences of the mean values and variances for the each material/lubricant combination are calculated and provided for the coefficient of friction data for (a) the design vs the run-in and (b) the used stud design vs the design categories. Significant difference here is calculated at the 95 percent confidence level.

#### C. Analysis of Variance (ANOVA) to Measure Stud-to-Stud Variations

An ANOVA is carried out for every lubricant/material combination to measure the significance of the stud-to-stud variation compared to the within stud variation of coefficient of friction. The application here is to establish whether the variations of the mean values for each stud are significantly different from the overall mean value. The inference here is, if there is no significant difference of mean values, the testing of five (5) can represent the coefficient of friction for all studs. A significant variation from stud-to-stud suggests that a tolerance interval, based on degrees of freedom of the testing, should be factored into the application of coefficient of friction values for all studs.

#### D. Ranking Criteria for All Stud/Lubricant Combinations.

The results of the lubricant coefficient of friction analyses described above were used to establish a relative ranking of lubricant candidates for each of the material combinations. See, for example, Tables I - VIII which list the summary statistics for each lubricant/material combination. A sort (ranking of lubricants) by features (e.g., range of coefficient of friction) was provided for consideration to choose potential lubricants for final recommendation of replacement for RLGMO. A small range is desirable since this would allow better predictable values of loading stresses for design calculations. A stud-to-stud variation would not be a desirable characteristic, since some adjustment must be made for use in design values provided.

### IV. RESULTS

As one criteria for ranking the lubricant coefficient of friction values, a tolerance interval (90 percent/95 percent from reference (a)) was calculated for each range of the design values of coefficient of friction for each lubricant/material combination and an overall composite ranking. This analysis was extended to used-stud design tolerance ranges and to the initial run-in tolerance ranges. The maximum and minimum values of the tolerance range were then obtained for each lubricant for all material combinations used. These values are listed in Tables IX through XIV. A composite plot of these ranges of coefficient of friction were developed for each of the three categories; run-in (Figure 1), design (Figure 2), and used-stud design (Figure 3). In addition, an individual plot of the relative ranking of the design coefficient of friction tolerance ranges for each material combination are provided in Figures 4 through 7. The data used for Tables I through XIV and Figures 1 through 7 are from the detailed datasets of coefficient of friction values in Attachments I through IV.

V. REFERENCES

- (a) Experimental Statistics, National Bureau of Standards Handbook 91, August 1, 1963

Attachments: I - Phase I - Coefficient of Friction Dataset: Alloy 625  
II - Phase I - Coefficient of Friction Dataset: Monel K-500 (K-Monel)/Monel 400  
III - Phase I - Coefficient of Friction Dataset: AISI 4140 Phosphate Coated  
IV - Phase I - Coefficient of Friction Dataset: AISI 4140 Alloy Steel (B7)

**TABLE I**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

**Material Combination: Inconel 625 Stud/Nut**

<b>LUBRICANT NUMBER</b>	<b>COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING LOADING VALUES UP TO 2/3 Yield</b>				<b>Stud-to Stud Change</b>	<b>Run-in vs. Design</b>	<b>Design vs Used Stud Design Mean</b>
	<b>Mean</b>	<b>Std Dev</b>	<b>Range</b>	<b>Normal Distr. Y/N</b>	<b>Signif Diff. Y/N*</b>	<b>Signif Diff. Y/N*</b>	<b>Signif Diff. Y/N*</b>
1	0.152	0.037	0.180	Yes	Yes	Yes	No
2	0.137	0.038	0.231	Yes	Yes	Yes	Yes
3	0.126	0.042	0.173	Yes	Yes	Yes	Yes
4	0.263	0.050	0.260	Yes	Yes	Yes	N/A **
5	0.139	0.043	0.195	Yes	Yes	Yes	Yes
6	0.143	0.032	0.122	No	No	Yes	No
7	0.174	0.037	0.164	Yes	No	Yes	No
8	0.127	0.029	0.125	Yes	Yes	Yes	No
9	0.179	0.048	0.234	Yes	Yes	Yes	Yes
10	0.127	0.028	0.129	Yes	No	Yes	Yes

\* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

\*\* For Lubricant 4 only 50 values are provided. Testing was difficult and completion of the used stud testing is pending.

TABLE II  
COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES  
Material Combination: Inconel 625 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN-IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.200	0.030	0.068	0.126	0.018	0.047
2	0.189	0.035	0.168	0.120	0.020	0.105
3	0.185	0.025	0.086	0.108	0.023	0.058
4	0.287	0.040	0.200	0.239	0.048	0.183
5	0.197	0.032	0.113	0.117	0.018	0.074
6	0.185	0.018	0.067	0.118	0.014	0.042
7	0.231	0.025	0.098	0.150	0.013	0.038
8	0.164	0.021	0.066	0.108	0.010	0.046
9	0.222	0.053	0.171	0.166	0.036	0.131
10	0.164	0.025	0.086	0.113	0.014	0.046

**TABLE III**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

**Material Combination: Monel K500/Monel 400 Stud/Nut**

<b>LUBRICANT NUMBER</b>	<b>COEFFICIENT OF FRICTION OVERALL - 5 STUDS, 4 LOADING</b>				<b>Stud-to Stud Change</b>	<b>Run-in vs. Design</b>	<b>Design vs Used Stud Design Mean</b>	
	<b>Mean</b>	<b>Std Dev</b>	<b>Range</b>	<b>Normal Distr. Y/N</b>	<b>Mean</b>	<b>Signif Diff. Y/N*</b>	<b>Mean</b>	<b>Signif Diff. Y/N*</b>
1	0.102	0.013	0.067	Yes	Yes	Yes		No
2	0.102	0.011	0.051	Yes	Yes	Yes		No
3	0.065	0.010	0.053	Yes	No	Yes		Yes
4	0.161	0.016	0.077	Yes	Yes	No		Yes
5	0.090	0.013	0.059	Yes	Yes	Yes		Yes
6	0.086	0.015	0.074	Yes	Yes	Yes		Yes
7	0.156	0.009	0.048	No	Yes	Yes		Yes
8	0.097	0.009	0.042	Yes	Yes	Yes		No
9	0.087	0.013	0.065	Yes	Yes	No		No
10	0.077	0.010	0.054	Yes	Yes	Yes		Yes

- \* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

**TABLE IV**  
**COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES**  
**Material Combination: K-Monel/Monel Stud/Nut**

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN-IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.114	0.013	0.041	0.099	0.010	0.035
2	0.108	0.009	0.031	0.101	0.009	0.031
3	0.074	0.012	0.042	0.065	0.008	0.032
4	0.150	0.010	0.034	0.153	0.014	0.053
5	0.103	0.010	0.040	0.088	0.010	0.036
6	0.097	0.015	0.056	0.085	0.015	0.058
7	0.154	0.011	0.048	0.160	0.009	0.030
8	0.102	0.008	0.026	0.094	0.008	0.026
9	0.087	0.009	0.030	0.087	0.014	0.037
10	0.088	0.009	0.027	0.075	0.006	0.020

TABLE V

## SUMMARY STATISTICS FOR LUBRICANT CANDIDATES

Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut

LUBRICANT NUMBER	COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING					Stud-to-Stud Change Mean	Run-in vs Design Mean	Design vs Used Stud Design Mean Signif Diff. Y/N*
	LOADING VALUES UP TO 2/3 Yield				Normal Distr. Y/N	Signif Diff. Y/N*		
	Mean	Std Dev	Range					
1	0.091	0.009	0.042	Yes	Yes	Yes	Yes	Yes
2	0.088	0.008	0.044	No	Yes	Yes	Yes	No
3	0.052	0.008	0.048	Yes	Yes	Yes	Yes	No
4	0.143	0.009	0.045	Yes	Yes	Yes	Yes	Yes
5	0.079	0.008	0.036	Yes	Yes	Yes	Yes	No
6	0.083	0.006	0.034	Yes	Yes	Yes	Yes	No
7	0.110	0.006	0.034	Yes	Yes	No	Yes	
8	0.090	0.005	0.028	Yes	Yes	No	No	No
9	0.098	0.018	0.072	Yes	Yes	No	No	No
10	0.082	0.007	0.050	Yes	Yes	Yes	Yes	Yes

- \* Significance is at the 95% confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

**TABLE VI**  
**COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES**  
**Material Combination: AISI 4140 Phosphate Coat/AISI 4140 Stud/Nut**

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.099	0.004	0.016	0.092	0.008	0.026
2	0.095	0.005	0.016	0.085	0.007	0.024
3	0.061	0.007	0.023	0.048	0.005	0.024
4	0.148	0.008	0.034	0.136	0.006	0.023
5	0.087	0.005	0.016	0.0757	0.006	0.023
6	0.089	0.005	0.019	0.080	0.005	0.016
7	0.109	0.007	0.034	0.107	0.005	0.014
8	0.088	0.004	0.013	0.090	0.005	0.015
9	0.106	0.018	0.051	0.102	0.020	0.061
10	0.089	0.008	0.040	0.083	0.005	0.022

**TABLE VII**  
**SUMMARY STATISTICS FOR LUBRICANT CANDIDATES**

**Material Combination: Alloy Steel (B7) Stud/Nut**

<b>LUBRICANT NUMBER</b>	<b>COEFFICIENT OF FRICTION OVERALL 5 STUDS, 4 LOADING</b>				<b>Stud-to-Stud Change</b>	<b>Run-in vs Design</b>	<b>Design vs Used Stud Design Mean</b>	
	<b>Mean</b>	<b>Std Dev</b>	<b>Range</b>	<b>Normal Distr. Y/N</b>	<b>Mean</b>	<b>Signif Diff. Y/N</b>	<b>Mean</b>	<b>Signif Diff. Y/N*</b>
1	0.105	0.009	0.032	Yes	N/A**	Yes		No
2	0.095	0.009	0.036	Yes	N/A	No		Yes
3	0.059	0.010	0.039	Yes	N/A	Yes		Yes
4	0.148	0.007	0.029	Yes	N/A	Yes		Yes
5	0.095	0.009	0.030	Yes	N/A	Yes		Yes
6	0.105	0.008	0.036	Yes	N/A	Yes		No
7	0.123	0.007	0.030	Yes	N/A	Yes		No
8	0.099	0.005	0.025	Yes	N/A	No		No
9	0.102	0.017	0.062	Yes	N/A	Yes		Yes
10	0.088	0.004	0.018	Yes	N/A	Yes		Yes

\* Significance is at the 95 % confidence level; i.e., a significant difference for the stud mean value outside of the 95% confidence interval of the overall mean value, or there is a significant difference between the design and run-in mean values at the 95% confidence level.

\*\* This material had only 2 studs tested, not 5 as with the other material combinations.

**TABLE VIII**  
**COEFFICIENT OF FRICTION RUN-IN AND DESIGN VALUES**  
**Material Combination: Alloy Steel (B7) Stud/Nut**

LUBRICANT NUMBER	COEFFICIENT OF FRICTION					
	RUN - IN LOADING			DESIGN LOADING		
	MEAN	STD DEV	RANGE	MEAN	STD DEV	RANGE
1	0.117	0.004	0.012	0.100	0.007	0.022
2	0.101	0.005	0.015	0.096	0.010	0.033
3	0.071	0.008	0.025	0.057	0.006	0.013
4	0.152	0.006	0.020	0.141	0.006	0.020
5	0.101	0.003	0.009	0.095	0.006	0.015
6	0.111	0.004	0.016	0.104	0.008	0.026
7	0.125	0.009	0.027	0.119	0.004	0.013
8	0.097	0.007	0.026	0.097	0.005	0.016
9	0.123	0.009	0.026	0.107	0.006	0.017
10	0.092	0.003	0.012	0.088	0.004	0.010

**Table IX. Initial Run-in Values: Tolerance Ranges**

90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION						INITIAL RUN-IN VALUES						SORT ON RANGE					
LUBR.	MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	4140 PHO MEAN	4140 PHO STD DEV	80/85 TOL LOW	80/85 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN					
6	0.185	0.018	0.140468	0.229532	0.089084	0.491427	0.098	0.004	0.078104	0.097696	0.019792	8	0.224909				
6	0.184	0.021	0.112946	0.215954	0.103908	0.633585	0.099	0.004	0.089104	0.108896	0.019782	1	0.189919				
7	0.231	0.025	0.16915	0.29285	0.1237	0.535498	0.095	0.005	0.08263	0.10737	0.02474	2	0.260421				
10	0.184	0.025	0.10215	0.22385	0.1237	0.754268	0.089	0.005	0.07663	0.10137	0.02474	6	0.277978				
3	0.185	0.025	0.12315	0.24685	0.1237	0.686649	0.087	0.005	0.07463	0.098937	0.02474	5	0.284388				
1	0.2	0.03	0.12578	0.27422	0.14844	0.7422	0.061	0.007	0.043682	0.078318	0.034686	3	0.367803				
5	0.197	0.032	0.117832	0.276168	0.158336	0.603736	0.109	0.007	0.091682	0.128318	0.034686	7	0.317761				
2	0.189	0.035	0.10241	0.27559	0.17318	0.916286	0.089	0.008	0.069208	0.108792	0.039584	10	0.444764				
4	0.287	0.04	0.18804	0.38598	0.19792	0.689617	0.148	0.008	0.128208	0.167792	0.039584	4	0.287459				
9	0.222	0.053	0.090878	0.253122	0.262244	1.181279	0.106	0.016	0.081468	0.150532	0.089084	9	0.840226				
MAT'L>> K MONEL/MONEL	MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	B7 ALLOY MEAN	STDEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	LUBRICANT	RANGE/ MEAN					
8	0.102	0.008	0.082208	0.121792	0.039584	0.388078	0.092	0.003	0.082946	0.101054	0.018108	10	0.186826				
9	0.087	0.009	0.084734	0.109266	0.044532	0.511862	0.101	0.003	0.091946	0.110054	0.018108	5	0.172827				
10	0.088	0.009	0.085734	0.110266	0.044532	0.508045	0.111	0.004	0.098928	0.123072	0.024144	6	0.211514				
2	0.108	0.009	0.085734	0.130286	0.044532	0.412333	0.117	0.004	0.104828	0.128072	0.024144	1	0.203359				
5	0.103	0.01	0.07826	0.12774	0.049498	0.480388	0.101	0.005	0.08891	0.111609	0.03016	2	0.283812				
4	0.15	0.01	0.12526	0.17474	0.049498	0.329867	0.152	0.006	0.133092	0.170108	0.030216	4	0.233263				
7	0.154	0.011	0.126786	0.181214	0.054428	0.353429	0.097	0.007	0.075874	0.118126	0.042252	8	0.435568				
3	0.074	0.012	0.044912	0.103688	0.059376	0.802376	0.071	0.008	0.046656	0.095144	0.048288	3	0.680113				
1	0.144	0.013	0.111638	0.176162	0.064324	0.446694	0.125	0.009	0.097838	0.152162	0.054324	7	0.434592				
6	0.097	0.015	0.05989	0.13411	0.07422	0.765155	0.123	0.009	0.095838	0.150162	0.054324	9	0.441659				

**Table X.** Initial Run-in Values; Tolerance Ranges**COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS**

SORT ON RANGE			
LUBRICANT	MIN	MAX	RANGE
8	0.075874	0.215954	0.14008
10	0.065734	0.22585	0.160116
6	0.05989	0.229532	0.169642
1	0.089104	0.27422	0.185116
2	0.08263	0.27559	0.19296
7	0.091682	0.29285	0.201168
5	0.07463	0.276168	0.201538
3	0.043682	0.24685	0.203168
4	0.12526	0.38596	0.2607
9	0.061468	0.353122	0.291654

**Table XI. Initial Design Values; Tolerance Ranges**

80%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION DESIGN VALUES						80%/95% TOL. SORT ON RANGE						80%/95% TOL. SORT ON RANGE					
LUBR.	MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE MEAN	RANGE MEAN	4140 PHO MEAN	4140 PHO STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANKED RANGE	LUBRICANT	RANGE/ MEAN			
6	INCONEL	0.108	0.01	0.04326	0.13274	0.04948	0.458148	0.107	0.005	0.09463	0.111837	0.02474	7	0.231215			
7		0.15	0.013	0.117838	0.162162	0.04324	0.428827	0.083	0.005	0.07063	0.09537	0.02474	10	0.289072			
6		0.118	0.014	0.083364	0.152638	0.039272	0.587051	0.08	0.005	0.06763	0.09237	0.02474	6	0.30925			
10		0.113	0.014	0.078364	0.147638	0.039272	0.613027	0.048	0.005	0.03563	0.08637	0.02474	3	0.515417			
1		0.128	0.016	0.081468	0.170532	0.039084	0.706857	0.09	0.005	0.07763	0.10237	0.02474	6	0.274889			
5		0.117	0.018	0.072468	0.161532	0.039064	0.761231	0.136	0.006	0.121156	0.150844	0.029686	4	0.216294			
2		0.12	0.02	0.07052	0.16948	0.038986	0.824687	0.076	0.006	0.061156	0.090844	0.028688	5	0.390632			
3		0.108	0.023	0.051098	0.164902	0.1113804	1.053741	0.085	0.007	0.087682	0.102318	0.034636	2	0.407482			
9		0.168	0.036	0.076936	0.255964	0.178128	1.07306	0.092	0.008	0.072208	0.111792	0.039584	1	0.430261			
4		0.239	0.046	0.120248	0.357752	0.237504	0.9893741	0.102	0.02	0.05252	0.15148	0.09898	9	0.970196			
90/95 TOL LOW						90/95 TOL MEAN						90/95 TOL LOW					
MAT'L>>	K MONEL/MONEL	MEAN	STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE MEAN	RANGE MEAN	B7 ALLOY MEAN	B7 ALLOY STD DEV	90/95 TOL LOW	90/95 TOL HIGH	RANKED RANGE	RANKED RANGE	LUBRICANT	RANGE/ MEAN		
10		0.075	0.006	0.060156	0.089844	0.0298688	0.39584	0.119	0.004	0.106928	0.131072	0.024144	7	0.202891			
8		0.094	0.008	0.074208	0.113792	0.039584	0.421108	0.088	0.004	0.075928	0.100072	0.024144	10	0.274364			
3		0.065	0.008	0.045208	0.084792	0.039584	0.609885	0.097	0.005	0.08191	0.11209	0.03018	8	0.311134			
2		0.101	0.009	0.078734	0.123268	0.044532	0.440911	0.095	0.006	0.076892	0.113108	0.036216	5	0.381221			
7		0.16	0.009	0.137734	0.182266	0.044532	0.279325	0.141	0.006	0.122892	0.159108	0.036216	4	0.256851			
5		0.088	0.01	0.06326	0.11274	0.04948	0.562273	0.057	0.006	0.0388892	0.075108	0.036216	3	0.635348			
1		0.099	0.01	0.07426	0.12374	0.04948	0.499798	0.107	0.007	0.088892	0.125108	0.036216	9	0.38467			
4		0.153	0.014	0.118364	0.187638	0.069272	0.452758	0.1	0.007	0.078874	0.121128	0.042252	1	0.42252			
9		0.087	0.014	0.052364	0.121636	0.069272	0.79623	0.104	0.008	0.079858	0.128144	0.048288	6	0.464308			
6		0.085	0.015	0.04789	0.12211	0.07422	0.873176	0.096	0.01	0.06562	0.12618	0.06036	2	0.62875			

Table XII. Initial Design Values; Tolerance Ranges

COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATE			
SORT ON RANGE			
LUBRICANT	MIN	MAX	RANGE
8	0.074208	0.13274	0.058532
10	0.060156	0.147636	0.08748
7	0.09463	0.182266	0.087636
1	0.072208	0.170532	0.098324
5	0.061156	0.161532	0.100376
2	0.06582	0.16948	0.10366
6	0.04789	0.152636	0.104746
3	0.03563	0.164902	0.129318
9	0.052364	0.255064	0.2027
4	0.118364	0.357752	0.2023939

**Table XIII. Used Stud Design Values; Tolerance Ranges**

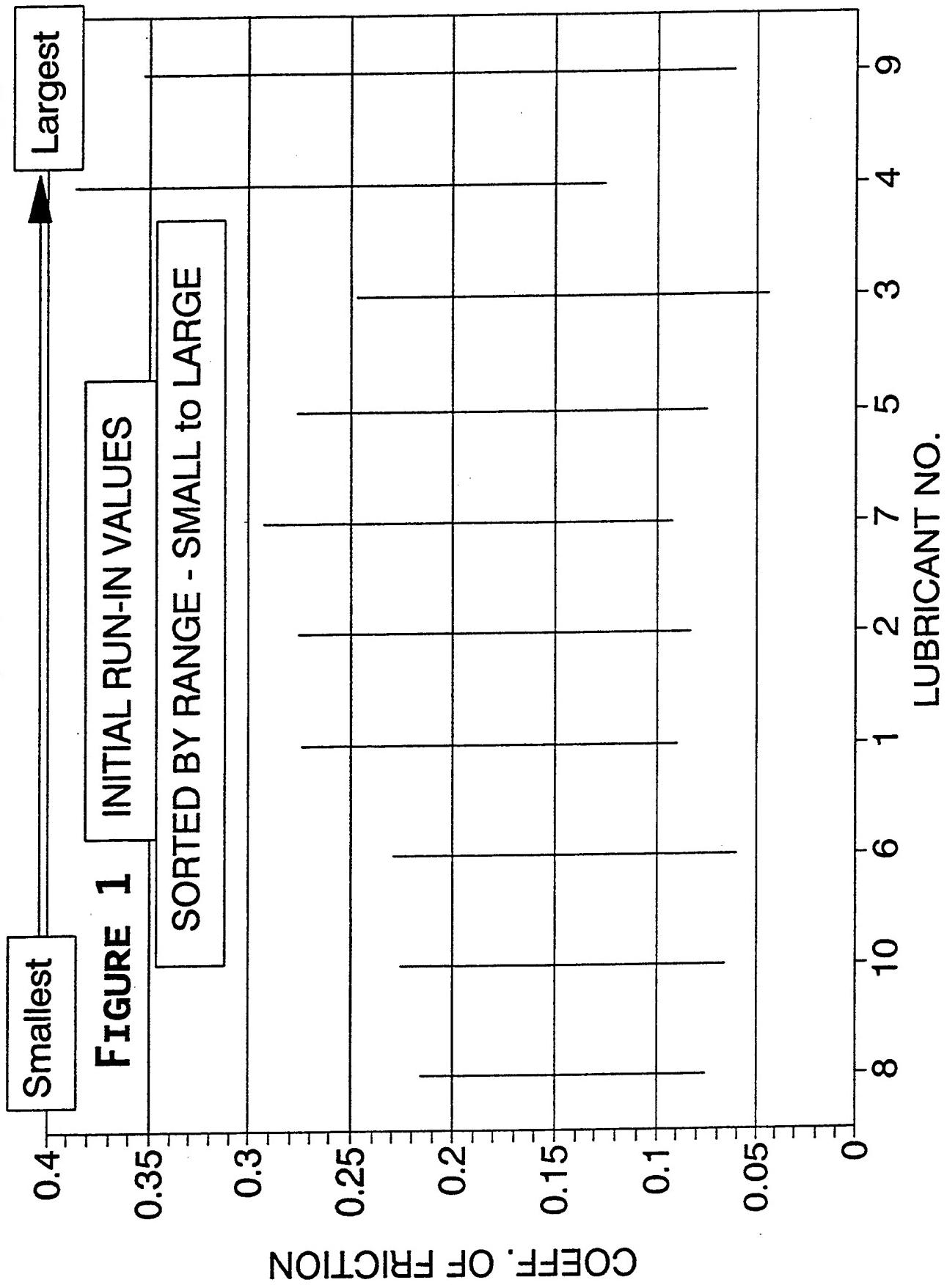
90%/95% TOLERANCE BANDS FOR COEFFICIENT OF FRICTION USED STUD DESIGN VALUES				SORT ON RANGE				90/95 TOL LOW HIGH				RANGE/ MEAN LUBRICANT				
LUBR.	MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	4140 PHO MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	87 ALLOY MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	87 ALLOY MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN
1	0.122	0.011	0.084786	0.149214	0.054428	0.446131	0.084	0.009	0.061734	0.108286	0.044532	1	0.530143			
2	0.105	0.011	0.077786	0.132214	0.054428	0.516362	0.082	0.009	0.059734	0.104266	0.044532	2	0.530173			
3	0.091	0.018	0.046468	0.135532	0.089064	0.976725	0.049	0.007	0.031682	0.086318	0.034636	3	0.706857			
4	N/A	N/A	0	0	0	0	0.148	0.011	0.120786	0.175214	0.054428	4	0.367757			
5	0.105	0.014	0.070384	0.139638	0.069272	0.659753	0.076	0.007	0.058682	0.085318	0.034636	5	0.455737			
6	0.116	0.012	0.085312	0.145688	0.089376	0.511862	0.079	0.005	0.08963	0.09137	0.02474	6	0.313165			
7	0.15	0.012	0.120312	0.178688	0.089376	0.39584	0.112	0.006	0.087156	0.128844	0.029688	7	0.285071			
8	0.11	0.019	0.082994	0.157006	0.094012	0.854655	0.039	0.007	0.072682	0.107318	0.034636	8	0.384844			
9	0.137	0.02	0.08752	0.18648	0.08896	0.722396	0.094	0.011	0.066786	0.121214	0.054428	9	0.579021			
10	0.104	0.009	0.081734	0.128266	0.044532	0.428192	0.079	0.004	0.089104	0.088896	0.019792	10	0.250532			
90/95 TOL LOW HIGH				RANGE/ MEAN				90/95 TOL LOW HIGH				RANGE/ MEAN LUBRICANT				
MAT'L > K MONEL/MONEL	MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	87 ALLOY MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	87 ALLOY MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN	87 ALLOY MEAN	STD DEV	90/95 TOL LOW HIGH	RANGE/ MEAN
1	0.095	0.011	0.067786	0.122214	0.054428	0.572926	0.096	0.004	0.083928	0.108072	0.024144	1	0.2515			
2	0.098	0.012	0.068312	0.127688	0.059376	0.605876	0.088	0.008	0.060898	0.115162	0.054324	2	0.617318			
3	0.057	0.006	0.042156	0.071844	0.029888	0.520842	0.052	0.005	0.036891	0.08709	0.03018	3	0.580385			
4	0.176	0.013	0.143638	0.208162	0.084324	0.385477	0.149	0.005	0.13391	0.18409	0.03018	4	0.20255			
5	0.083	0.007	0.065682	0.108318	0.034636	0.417301	0.087	0.007	0.065874	0.108126	0.042252	5	0.485655			
6	0.077	0.009	0.054734	0.099266	0.044532	0.576338	0.103	0.011	0.069802	0.136198	0.066396	6	0.644621			
7	0.153	0.006	0.138156	0.167844	0.029888	0.194039	0.121	0.004	0.108928	0.133072	0.024144	7	0.199537			
8	0.094	0.01	0.06926	0.111874	0.04948	0.526383	0.1	0.004	0.087928	0.112072	0.024144	8	0.24144			
9	0.095	0.013	0.052638	0.117162	0.064324	0.756753	0.086	0.011	0.052802	0.119198	0.066396	9	0.772047			
10	0.075	0.008	0.080156	0.089844	0.029888	0.39584	0.084	0.003	0.074946	0.089304	0.018108	10	0.215571			

Table XIV. Used Stud Design Values; Tolerance Ranges

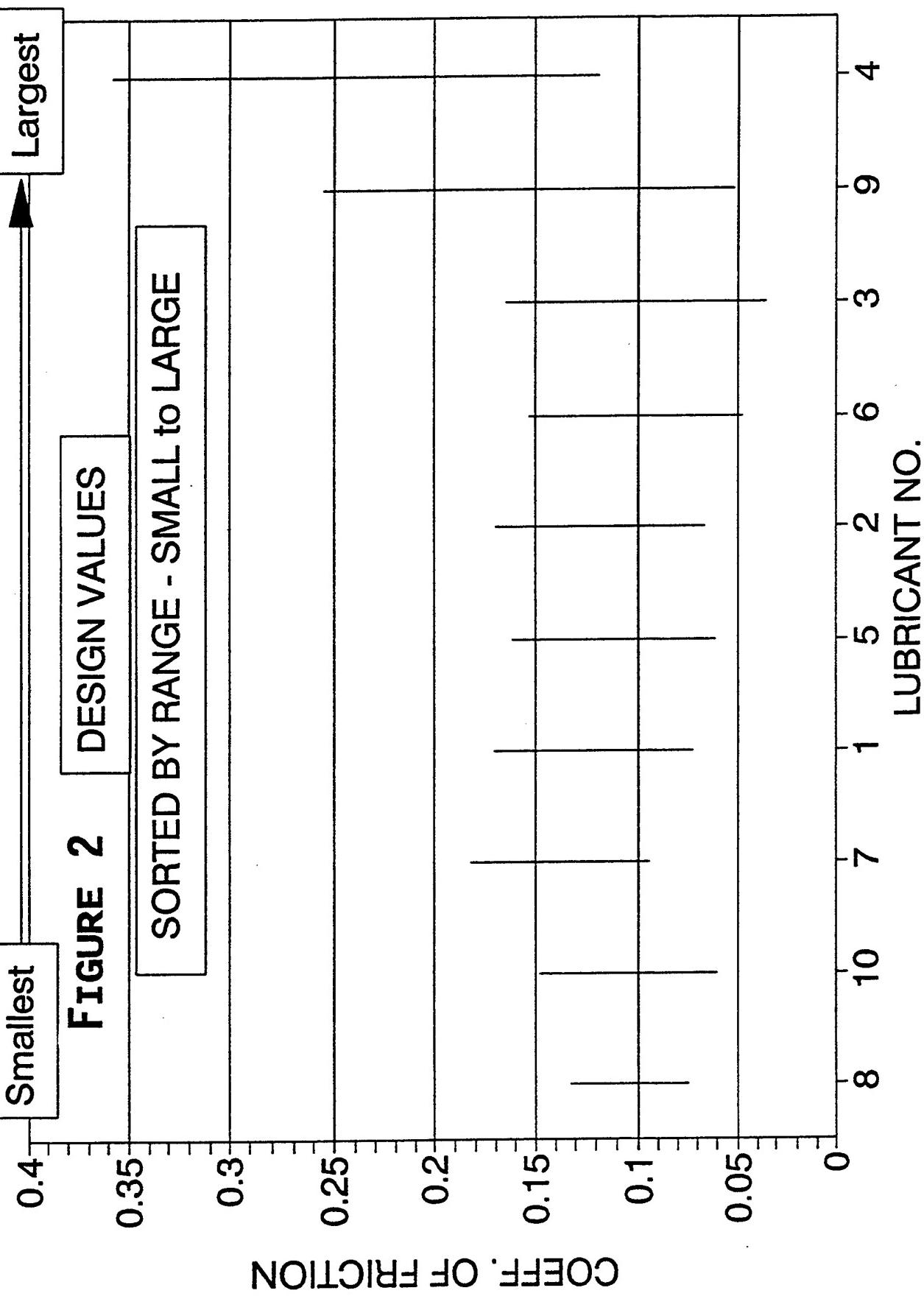
COMPOSITE MATERIALS - MIN/MAX 90/95 TOLERANCE - ALL FOUR MATERIALS

LUBRICANT	SORT ON RANGE	MIN	MAX	RANGE
4	n/a	n/a	n/a	n/a
10	0.060156	0.126266	0.06611	
2	0.059734	0.132214	0.07248	
5	0.058682	0.139636	0.080954	
7	0.097156	0.179688	0.082532	
1	0.061734	0.149214	0.08748	
6	0.054734	0.145688	0.090954	
8	0.062994	0.157006	0.094012	
3	0.031682	0.135532	0.10385	
9	0.052802	0.018648	0.133678	

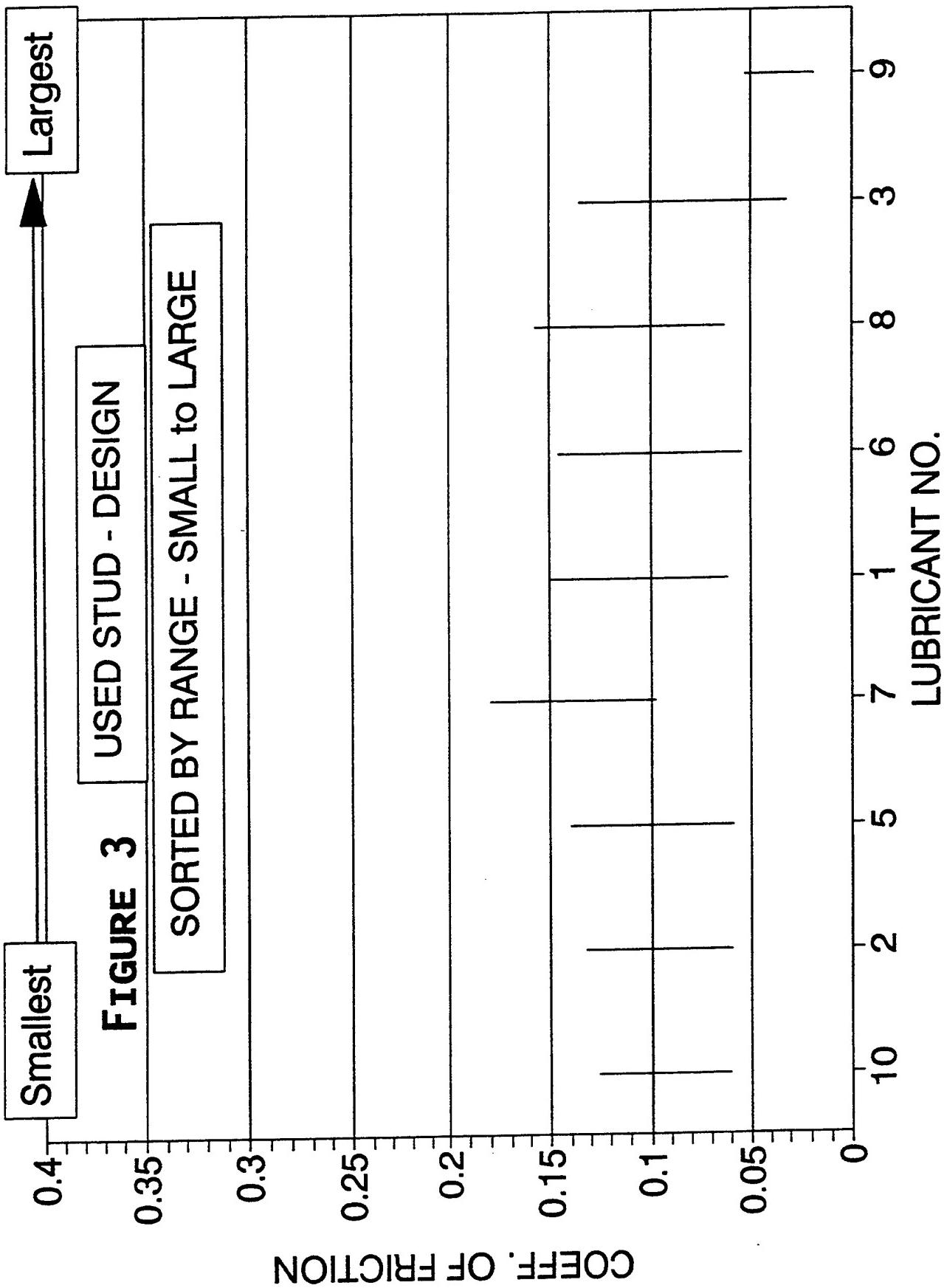
# COMPOSITE - 4 MAT'LS



# COMPOSITE-4 MAT'L'S



# COMPOSITE - 4 MAT'LS



# INCONEL

Smallest

Largest

FIGURE 4 DESIGN VALUES

SORTED BY RANGE - SMALL to LARGE

0.4

0.35

0.3

0.25

0.2

0.15

0.1

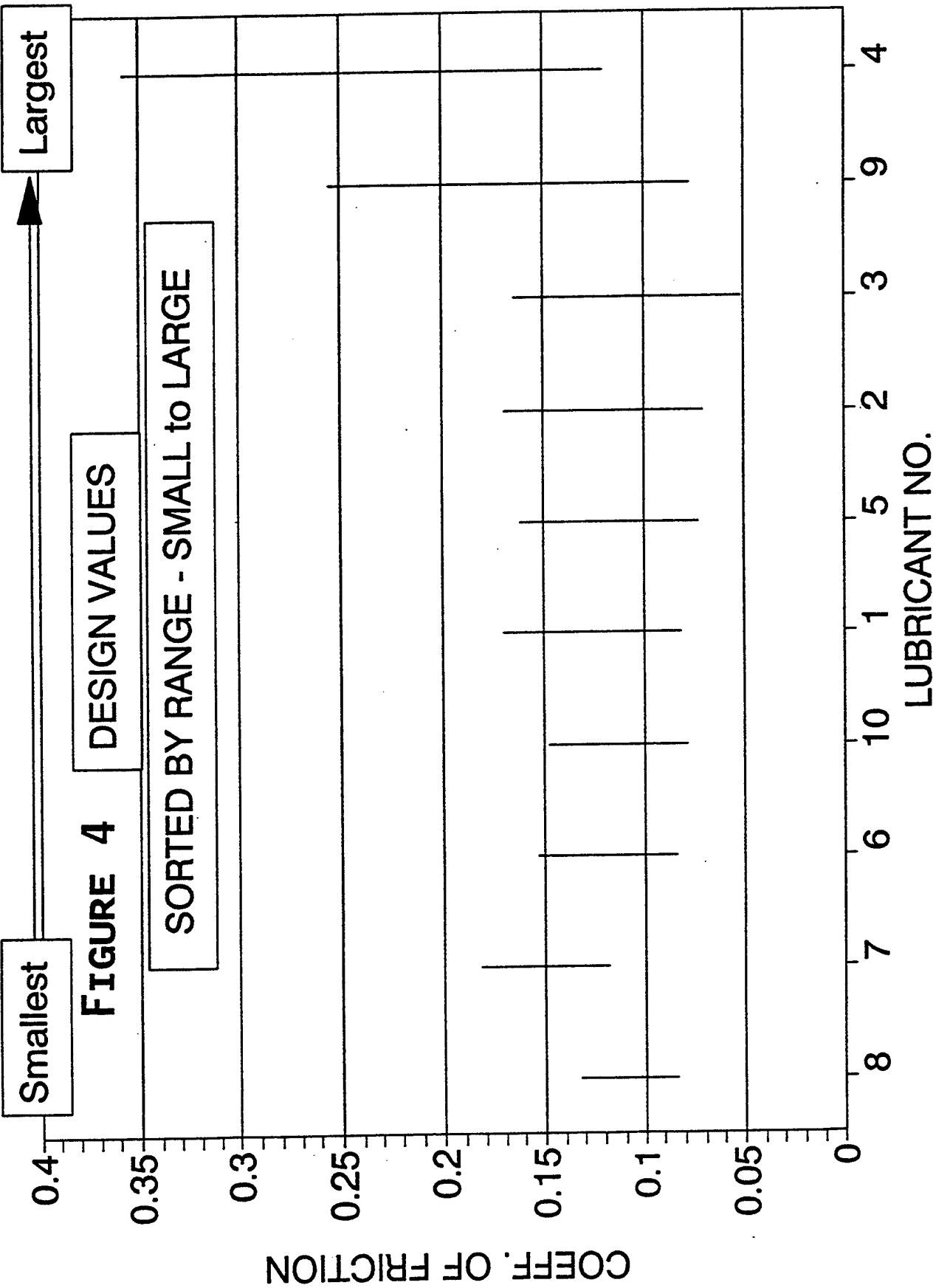
0.05

0

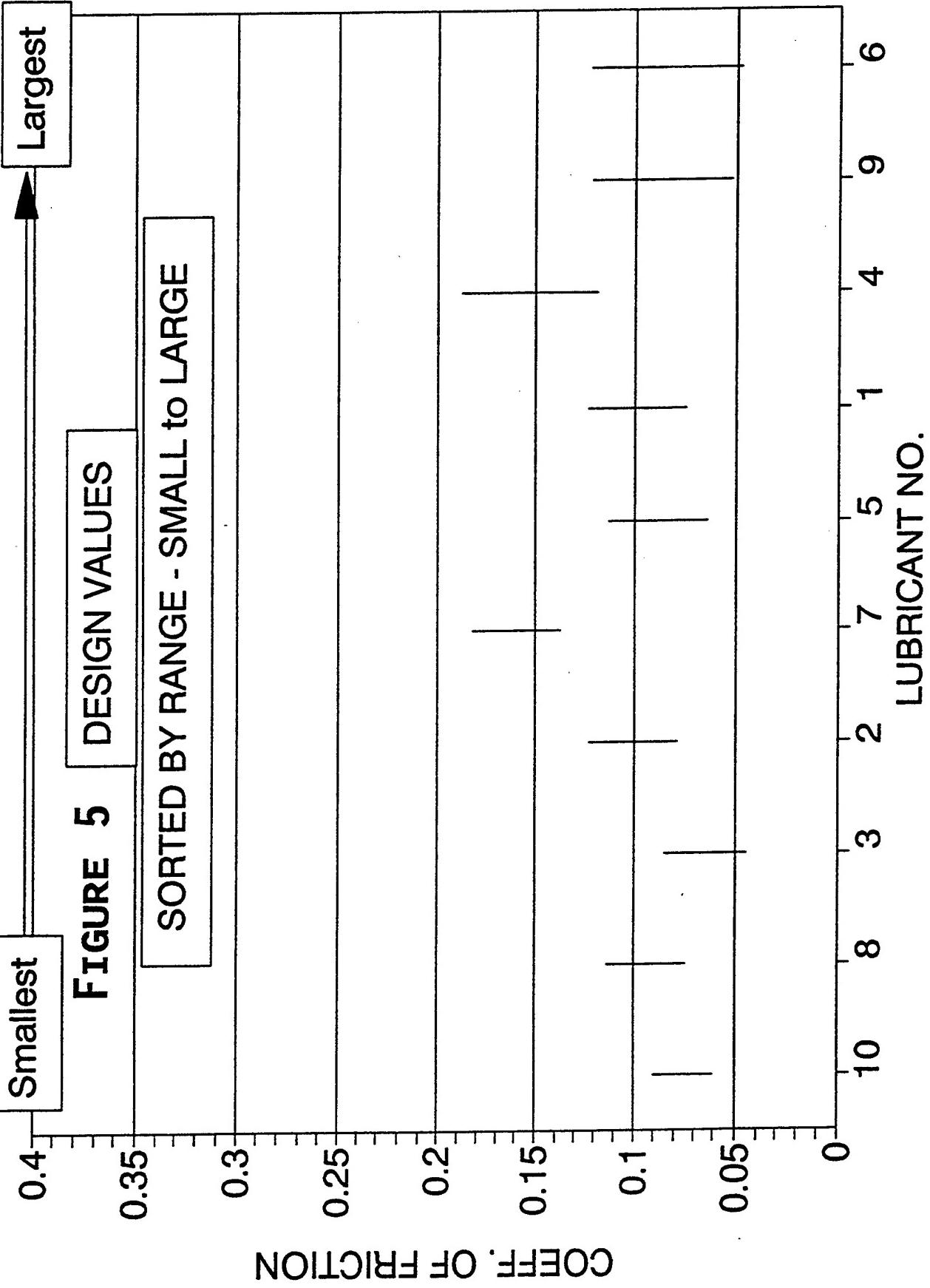
COEFF. OF FRICTION

4  
9  
3  
2  
1  
5  
10  
6  
7  
8  
0

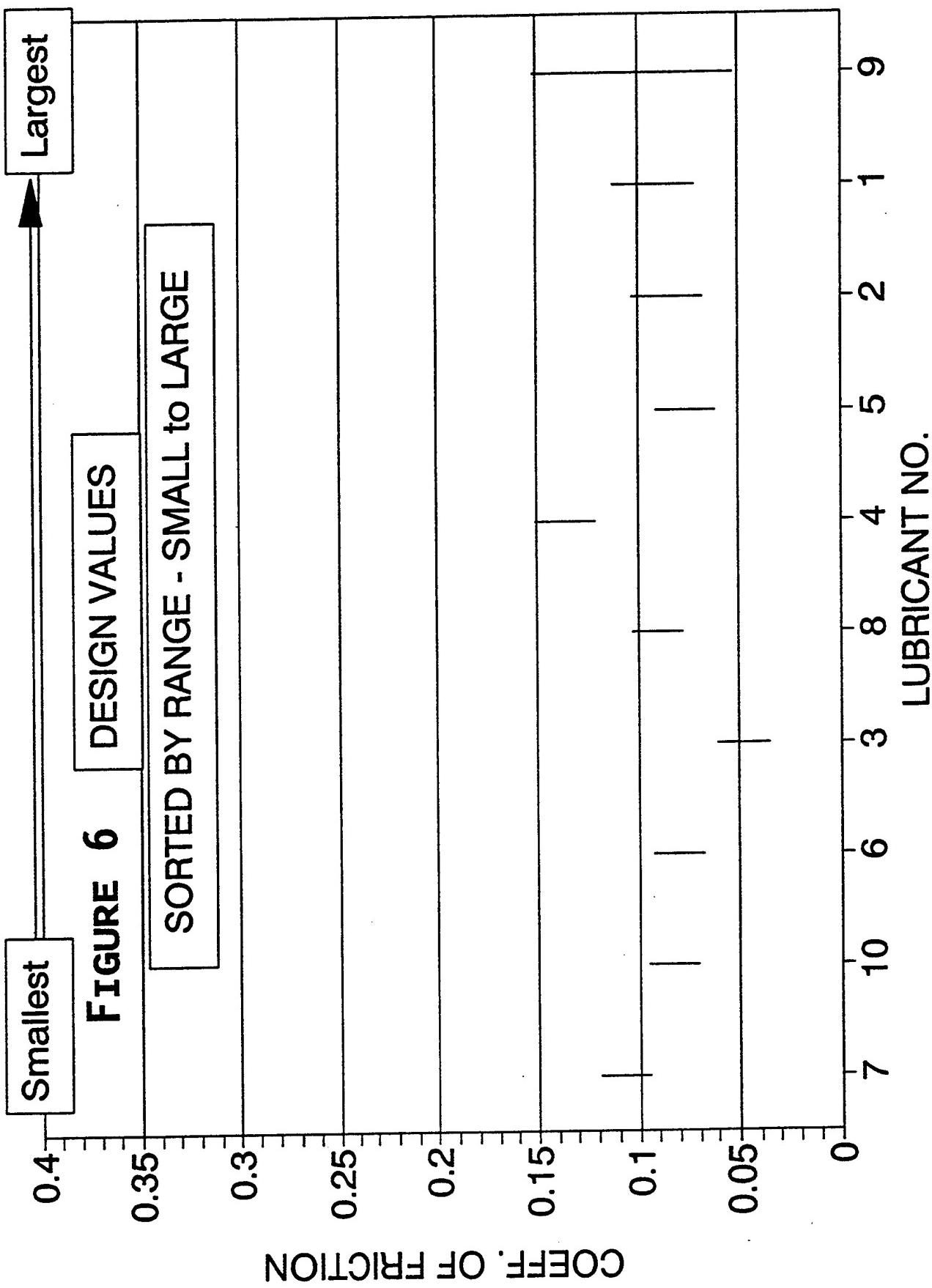
LUBRICANT NO.



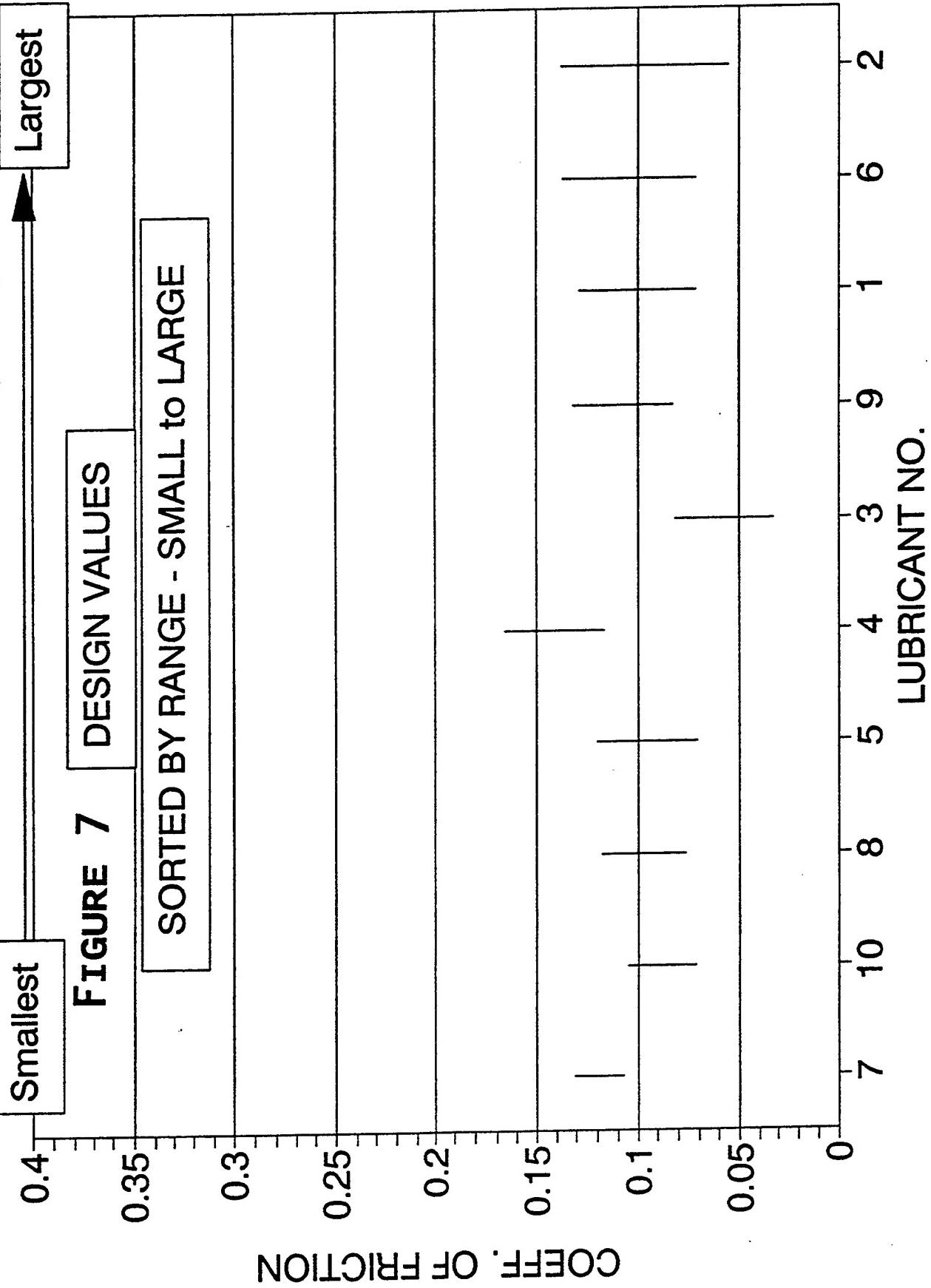
# K MONEL/MONEL



# AlSi 4140 PHOSPHATE



# ALLOY STEEL (B7)



## ATTACHMENT I

### Phase I - Coefficient of Friction Dataset

#### Alloy 625

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Alloy 625 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

**Table 1 Summary Statistics for 11**

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD	DEVIATION	TEST FOR MEAN		TEST FOR VARIANCE	
								t-TEST	t* = 1.68	F-TEST	F* = 1.98
0.206176	0.258768	0.276194	0.178885	0.182788							
0.18079	0.220041	0.249612	0.159115	0.184729							
0.176099	0.215785	0.225989	0.157524	0.201812	RUN-IN	0.189613	0.028919				
0.174479	0.193363	0.197991	0.195886	0.222039							
0.171377	0.185481	0.19643	0.175111	0.205186	XXXXXXXXXXXXXX						
0.162811	0.163275	0.171081	0.10072	0.139838							
0.109772	0.123899	0.139391	0.095936	0.125574							
0.1112347	0.118897	0.136119	0.105695	0.121656	DESIGN	0.126179	0.017637				
0.1119857	0.110578	0.141584	0.119887	0.127742							
0.1228863	0.111324	0.142914	0.125739	0.135889	XXXXXXXXXXXXXX						
0.167178	0.171081	0.182788	0.12811	0.151559							
0.141365	0.159115	0.166989	0.133471	0.155172	USED STUD RUN-IN						
0.145575	0.162833	0.169467	0.137605	0.173446							
0.14352	0.154167	0.159973	0.145457	0.175446							
0.13745	0.14597	0.148213	0.144474	0.160172	XXXXXXXXXXXXXX						
0.103549	0.147653	ERR	0.116376	0.143746							
0.101867	0.127849	ERR	0.111748	0.129523	USED STUD DESIGN						
0.109687	0.118997	ERR	0.117687	0.130961							
0.1119857	0.117647	ERR	0.117847	0.126733	XXXXXXXXXXXXXX						
0.124958	0.121634	ERR	0.117147	0.124177	OVERALL						
MEAN	0.140274	0.156699	0.180147	0.133934	0.155809	0.03083	0.152	0.037			
STD DEV	0.029693	0.041377	0.042456	0.026789							

TABLE 2: A TABLE2; ALLOY TYPE1, LUBRICANT NO.2

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.31901	0.188768	0.171157	0.256881	0.217958	0.16284	0.188693	0.055414		
0.222208	0.172897	0.16313	0.208437	0.176177	RUN-IN				
0.198084	0.17485	0.17485	0.190448	0.161979					
0.183559	0.177457	0.173589	0.178392	0.15127	XXXXXXXXXXXXXX				
0.172347	0.167717	0.165475	0.168464						
0.19847	0.108597	0.116427	0.104681	0.120341					
0.135504	0.094	0.105867	0.101912	0.101912					
0.116389	0.109735	0.112397	0.112171	0.112397	DESIGN	0.119887	0.019862	8.497643	3.258124
0.110627	0.112073	0.11871	0.138858	0.117699			YES		
0.123451	0.125014	0.132828	0.134388	0.119544	XXXXXXXXXXXXXX				
0.186768	0.1399	0.128166	0.159441	0.124254					
0.141427	0.121679	0.12563	0.137479	0.10389	USED STUD RUN-IN				
0.14431	0.12171	0.132348	0.142982	0.108405					
0.134865	0.124769	0.134865	0.148426	0.107596					
0.130482	0.127358	0.132826	0.149028	0.1086	XXXXXXXXXXXXXX				
0.128166	0.092929	0.092929	0.108597	0.104681					
0.105867	0.092022	0.094	0.101912	0.088065	USED STUD DESIGN				
0.113728	0.097754	0.097754	0.108405	0.092427					
0.12073	0.104564	0.102542	0.11871	0.098476			YES	3.316556	3.343545
0.116417	0.110945	0.105472	0.121888	0.109381	XXXXXXXXXXXXXX				
MEAN	0.155136	0.128574	0.139217	0.144852	0.125295	OVERALL			
STD DEV	0.051775	0.030889	0.023843	0.040161	0.034525	0.136581	0.038906		

DESIGN VS RUN-IN

t YES

DESIGN VS USED STUD DESIGN

t YES

TABLE 3: ALLOY TYPE I, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD DEVIATION	t-TEST	F-TEST
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD DEVIATION	t*-TEST	F*-TEST
0.237428	0.175061	0.19847	0.229842	0.167252	0.184714	0.025132	t*=1.68	F*=1.98
0.220241	0.159185	0.202533	0.208437	0.151295				95% Conf
0.203173	0.158922	0.208261	0.190448	0.168215				
0.174556	0.173589	0.205484	0.163914	0.171654				
0.155757	0.176176	0.200167	0.148278	0.167717	XXXXXXXXXXXXXXXXXXXX			
0.120341	0.100764	0.159441	0.08509	0.08117				
0.101912	0.080148	0.139453	0.082128	0.080148			t	F
0.113728	0.087099	0.140324	0.084434	0.087099	DESIGN	0.107506	0.023478	11.22467 1.14594
0.110627	0.116689	0.144553	0.088397	0.093443			YES	NO
0.109381	0.127358	0.138292	0.093769	0.114854	XXXXXXXXXXXXXXXXXXXX			
0.108597	0.08117	0.175061	0.092929	0.124254				
0.113774	0.086086	0.159185	0.084107	0.133553	USED STUD RUN-IN			
0.129689	0.105742	0.152281	0.081769	0.145639		0.119838 0.027632		
0.128808	0.113659	0.138709	0.080282	0.150383				
0.121107	0.109381	0.13595	0.090804	0.152018	XXXXXXXXXXXXXXXXXXXX			
0.073328	0.069405	0.132078	0.073328	0.08117				
0.066287	0.070248	0.103867	0.064308	0.076189	USED STUD DESIGN	t	F	
0.088431	0.079104	0.100417	0.077771	0.084434		0.091014 0.018451	2.761431 1.618091	
0.094454	0.085363	0.114669	0.103953	0.095465			YES	NO
0.105381	0.092434	0.12267	0.110163	0.103842	XXXXXXXXXXXXXXXXXXXX			
					OVERALL			
MEAN	0.12905	0.112529	0.166611	0.112028	0.121488	0.125768	0.042778	
STD DEV	0.046513	0.03695	0.028587	0.046595	0.035324			

TABLE 4: ALLOY 1, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.307375	0.276316	0.249102	0.276316	0.418584						
0.282827	0.279162	0.287576	0.287576	0.348837						
0.260976	0.276776	0.279206	0.241303	0.340332	RUN-IN	0.287076	0.040144			
0.284333	0.308375	0.316063	0.257553	0.315102						
0.288956	0.288956	0.273911	0.219964	0.272327	XXXXXXXXXXXXXX					
0.2225748	0.252992	0.342262	0.167252	0.24132						
0.202533	0.234004	0.307386	0.159185	0.236899						
0.211589	0.2286	0.313061	0.172196	0.250031	DESIGN	0.238642	0.048284	$t$ F YES	$t$ F NO	DESIGN VS RUN-IN XXXXXXXXXXXXXX
0.250326	0.263875	0.287219	0.175523	0.25936						
0.2188408	0.233962	0.29934	0.169959	0.255717	XXXXXXXXXXXXXX					
					USED STUD RUN-IN	0	0			
					XXXXXXXXXXXXXX					
					USED STUD DESIGN	0	0			DESIGN VS USED STUD DESIGN
					XXXXXXXXXXXXXX					
					OVERALL					
MEAN	0.126874	0.132151	0.195008	0.104841	0.147028					
STD DEV	0.132584	0.136804	0.144565	0.11203	0.156315					
					0.282859	0.050295				

TABLE 5: ALLOY 1, LUBRICANT NO. 5

	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.163347	0.276316	0.19457	0.225748	0.252982						
0.153268	0.251686	0.172987	0.208437	0.210405						
0.169542	0.236223	0.172196	0.203173	0.206389	RUN-IN	0.196735	0.032197			
0.163914	0.206409	0.175523	0.193448	0.201781						
0.155757	0.187024	0.167717	0.183972	0.185563	XXXXXXXXXXXXXX					
0.120341	0.159441	0.08509	0.128168	0.120341						
0.101912	0.12863	0.092022	0.13353	0.10389						
0.105742	0.116389	0.096423	0.146988	0.105742	DESIGN	0.117324	0.018045	1	F	
0.107596	0.110627	0.103553	0.143584	0.116689				YES	YES	3.183422
0.107036	0.119544	0.116417	0.144538	0.121888	XXXXXXXXXXXXXX					
0.086847	0.214062	0.100764	0.120341	0.178984						
0.105867	0.161158	0.095979	0.117727	0.159185	USED STUD RUN-IN					
0.12171	0.156296	0.103008	0.129689	0.160249				0.134621	0.029662	
0.132846	0.153268	0.103553	0.129818	0.153268						
0.133607	0.150522	0.114072	0.130482	0.142196	XXXXXXXXXXXXXX					
0.08117	0.1399	0.08901	0.100764	0.1399						
0.086086	0.1111798	0.088065	0.105887	0.113774	USED STUD DESIGN			1	F	
0.089763	0.113728	0.095091	0.105742	0.111066				0.10534	0.014429	-2.5935 1.564176
0.095465	0.112648	0.096476	0.112648	0.106585				YES	NO	
0.103028	0.113291	0.098954	0.115638	0.107036	XXXXXXXXXXXXXX					
MEAN	0.119742	0.160798	0.126263	0.143984	0.149925					
STD DEV	0.028144	0.051371	0.038026	0.037777	0.045574	OVERALL		0.138505	0.04279	

TABLE 6: ALLOY 1, LUBRICANT NO. 6

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.217958	0.19457	0.210165	0.210165	0.182867			t-TEST $t^* = 1.68$	F-TEST $F^* = 1.88$ 95% Conf
0.204501	0.1789	0.172987	0.202533	0.157213				
0.200629	0.187902	0.18281	0.187902	0.168922	RUN-IN	0.184676	0.017745	
0.192522	0.185112	0.192522	0.178425	0.155204				
0.181911	0.173694	0.185563	0.170708	0.15127	XXXXXXXXXXXXXXXXXXXX			
0.112512	0.120341	0.120341	0.138989	0.128168				
0.097957	0.10389	0.10389	0.12679	0.105867				
0.099086	0.111066	0.111066	0.12838	0.116389	DESIGN	0.118394	0.013559	
0.103553	0.107596	0.139709	0.139858	0.111972				
0.1116417	0.1113291	0.15127	0.131263	0.126576	XXXXXXXXXXXXXXXXXXXX			
0.19457	0.155534	0.182867	0.147718	0.19457				
0.167073	0.141427	0.143401	0.151295	0.165102	USED STUD RUN-IN			
0.162905	0.148968	0.136336	0.152281	0.156286				
0.151331	0.147458	0.137772	0.144553	0.145521				
0.144538	0.134388	0.13673	0.13673	0.137511	XXXXXXXXXXXXXXXXXXXX			
0.1399	0.100764	0.147718	0.104881	0.124254				
0.117727	0.095979	0.115751	0.097957	0.111798	USED STUD DESIGN			
0.116389	0.115058	0.111066	0.10398	0.117719				
0.109617	0.129818	0.11871	0.107598	0.11871				
0.110945	0.133697	0.121888	0.110945	0.118762	XXXXXXXXXXXXXXXXXXXX			
MEAN	0.147102	0.138868	0.153829	0.142886	OVERALL			
STD DEV	0.040202	0.031493	0.032008	0.032946	0.024767		0.142921	0.032045

TABLE 7: ALLOY I, LUBRICANT NO.7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.237428	0.202389	0.276316	0.276316	0.295733				
0.220241	0.230072	0.251686	0.255813	0.234004				
0.22733	0.222246	0.246381	0.238763	0.219704	RUN-IN	0.231141	0.025372	
0.220288	0.215663	0.231344	0.211962	0.210111				
0.211114	0.200897	0.244065	0.197977	0.200897	XXXXXXXXXXXXXXXXXXXXXX			
0.1399	0.186768	0.171157	0.171157	0.171157				
0.143401	0.149321	0.143401	0.13353	0.141427				
0.140324	0.15361	0.138995	0.138995	0.140324	DESIGN	0.1603	0.013272	t 14.11643 F 3.654582
0.154236	0.158108	0.141647	0.140553	0.137772			YES	YES
0.155757	0.159495	0.146782	0.154261	0.141415	XXXXXXXXXXXXXXXXXXXXXX			
0.167252	0.182867	0.179964	0.163347	0.182867				
0.161158	0.15524	0.159185	0.161158	0.163113	USED STUD RUN-IN			
0.172196	0.156266	0.162905	0.164232	0.161577				
0.166817	0.163947	0.168882	0.167785	0.162947				
0.16398	0.16398	0.165475	0.163232	0.161758	XXXXXXXXXXXXXXXXXXXXXX			
0.1399	0.151626	0.151626	0.143809	0.178964				
0.131555	0.131555	0.139453	0.153268	0.157213	USED STUD DESIGN			
0.136336	0.146868	0.140324	0.160249	0.152281				
0.140678	0.156236	0.140678	0.165885	0.156172			NO	NO
0.143757	0.163232	0.144538	0.166222	0.162786	XXXXXXXXXXXXXXXXXXXXXX			
MEAN	0.168682	0.172373	0.189212	0.176814	0.17611	0.039189	OVERALL	
STD DEV	0.034557	0.022948	0.047352	0.039414	0.174154	0.037106		

TABLE 8: ALLOY/LUBRICANT NO. 8

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.19067	0.151626	0.206267	0.1399	0.175061			t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$ 95% Conf
0.192689	0.151295	0.18284	0.127605	0.153268				
0.196812	0.177503	0.172196	0.136336	0.150953	RUN-IN	0.163804	0.02143	
0.184186	0.173589	0.168817	0.141647	0.144553				
0.178176	0.159495	0.158	0.142198	0.141415	XXXXXXXXXXXXXXXXXXXX			
0.108597	0.098847	0.120341	0.096847	0.100764				DESIGN VS RUN-IN
0.101912	0.105867	0.10389	0.092022	0.084107			t	F
0.109735	0.112397	0.112397	0.101749	0.098423	DESIGN	0.107545	0.010072	11.87954 4.527052
0.11972	0.114669	0.110627	0.108808	0.103553			YES	YES
0.130482	0.115636	0.115636	0.114854	0.110945	XXXXXXXXXXXXXXXXXXXX			
0.167252	0.151626	0.151626	0.093929	0.086847				
0.13353	0.135504	0.13353	0.088065	0.085979	USED STUD RUN-IN			
0.138995	0.142982	0.137666	0.100417	0.107074				
0.140678	0.147458	0.142615	0.102542	0.112646				
0.146034	0.139073	0.139854	0.107036	0.114854	XXXXXXXXXXXXXXXXXXXX			DESIGN VS USED STUD DESIGN
0.147718	0.112512	0.132078	0.085909	0.081117			t	F
0.131555	0.094	0.103821	0.105987	0.082128	USED STUD DESIGN			
0.135907	0.105742	0.113728	0.086423	0.089763			0.110464	0.018756 0.685551 3.46767
0.138741	0.111638	0.115679	0.098498	0.096476			NO	YES
0.141415	0.114072	0.115636	0.106254	0.100583	XXXXXXXXXXXXXXXXXXXX			
MEAN	0.146695	0.130877	0.143662	0.109244	0.111928			OVERALL
STD DEV	0.028947	0.025346	0.028529	0.018369	0.028724			0.127121 0.029144

TABLE 9: ALLOY I, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.167252	0.19847	0.178984	0.326764	0.217958				
0.149321	0.192889	0.18284	0.285428	0.280072				
0.156266	0.201901	0.203173	0.28827	0.25368	RUN-IN	0.022099	0.05263	
0.154236	0.197152	0.220288	0.283953	0.283975				
0.152796	0.212573	0.255717	0.319916	0.288956	XXXXXXXXXXXXXX			
0.092929	0.19847	0.171157	0.178984	0.147718				
0.095979	0.200564	0.161158	0.171016	0.141427				
0.104411	0.194266	0.177503	0.181483	0.150953	DESIGN	0.166164	0.036231	
0.114669	0.215663	0.197152	0.174556	0.172622				
0.128992	0.223853	0.203817	0.172947	0.181911	XXXXXXXXXXXXXX			
0.19067	0.182867	0.167252	0.163347	0.147718				
0.18087	0.18678	0.174958	0.15524	0.147348	USED STUD RUN-IN			
0.191721	0.198084	0.214619	0.162905	0.177503			0.190711	0.029152
0.211036	0.213812	0.237673	0.188752	0.204558				
0.24018	0.212573	0.282611	0.164727	0.219964	XXXXXXXXXXXXXX			
0.155534	0.128166	0.128166	0.167252	0.108597				
0.147348	0.12563	0.127605	0.141427	0.101912	USED STUD DESIGN			
0.158922	0.132348	0.136336	0.140324	0.107074			0.137453	0.020245
0.170687	0.141647	0.140678	0.141647	0.109617				-3.45891 3.202715
0.178176	0.142977	0.155009	0.137511	0.111727	XXXXXXXXXXXXXX			
MEAN	0.157095	0.185024	0.199925	0.194822	0.17426	0.179107	0.047711	
STD DEV	0.03759	0.031901	0.030744	0.061986	0.058993			
					OVERALL			

TABLE 10: ALLOY TYPE I, LUBRICANT NO.10

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.217958	0.189768	0.217958	0.129168	0.1399					
0.18087	0.177016	0.204501	0.137479	0.13353					
0.164232	0.179869	0.189175	0.158266	0.132348	RUN-IN	0.164031	0.025156		
0.154236	0.172622	0.168817	0.159076	0.139709					
0.144538	0.165475	0.152018	0.168464	0.146762	XXXXXXXXXXXXXX				
0.100764	0.120341	0.100764	0.120341	0.092929					
0.094	0.111788	0.101912	0.109821	0.095979					
0.093759	0.131019	0.109735	0.116389	0.107074	DESIGN	0.113401	0.013923	8.804803	3.284683
0.101531	0.139709	0.128808	0.12174	0.114689			YES		
0.103981	0.139073	0.129701	0.123451	0.120325	XXXXXXXXXXXXXX				
0.1116427	0.120341	0.128166	0.120341	0.128166					
0.1115751	0.109821	0.123654	0.12958	0.127605	USED STUD RUN-IN				
0.12804	0.1117719	0.137666	0.133676	0.132348					
0.12073	0.124769	0.131897	0.136903	0.140678			0.126361	0.008017	
0.1117799	0.1257795	0.127358	0.129701	0.139854	XXXXXXXXXXXXXX				
0.100764	0.08901	0.104681	0.092929	0.108597					
0.101912	0.086065	0.101912	0.094	0.095979	USED STUD DESIGN				
0.104411	0.093759	0.108405	0.105742	0.108405			0.104191	0.009164	2.762597
0.103553	0.098498	0.115679	0.107598	0.114669			YES		2.3036292
0.099769	0.113291	0.124232	0.110163	0.118762	XXXXXXXXXXXXXX				
					OVERALL				
MEAN	0.123241	0.129488	0.143338	0.125088	0.121915		0.128996	0.027583	
STD DEV	0.03289	0.029883	0.035985	0.020125	0.016606		R=0.1289		

## ATTACHMENT II

### **Phase I - Coefficient of Friction Dataset**

#### **Monel K-500 (K-Monel)/Monel 400**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every Monel K-500 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1: ALLOY M, LUBRICANT NO. 1

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE
0.108455	0.097855	0.094721	0.121113	0.097655					
0.113048	0.096638	0.102608	0.130931	0.09813					
0.125574	0.115489	0.108426	0.138517	0.111453	RUN-IN	0.114448	0.012958		
0.117683	0.118416	0.106684	0.138748	0.114017					
0.11954	0.126285	0.108293	0.131343	0.121789	XXXXXXXXXXXXXXXXXXXX				
0.088852	0.100589	0.082981	0.092981	0.091787					
0.089176	0.102606	0.086119	0.087683	0.095146					
0.098392	0.107417	0.092274	0.095342	0.103338	DESIGN	0.089245	0.010327	1	F
0.100382	0.110351	0.092531	0.103017	0.108884					
0.108855	0.117853	0.098483	0.113917	0.118415	XXXXXXXXXXXXXXXXXXXX				
0.088852	0.0911787	0.088852	0.100589	0.091787					
0.095146	0.098113	0.087683	0.095146	0.093653	USED STUD RUN-IN				
0.10237	0.108426	0.101361	0.098332	0.101381					
0.10375	0.109618	0.105217	0.098615	0.102283					
0.109418	0.115604	0.109418	0.101419	0.103918	XXXXXXXXXXXXXXXXXXXX				
0.085917	0.088852	0.071235	0.088852	0.085917					
0.090668	0.095146	0.081711	0.086119	0.083204	USED STUD DESIGN				
0.10237	0.106408	0.100352	0.087224	0.097523					
0.104484	0.105951	0.103017	0.087779	0.093349					
0.110543	0.113355	0.111105	0.091435	0.108043	XXXXXXXXXXXXXXXXXXXX				
MEAN	0.103056	0.106329	0.097715	0.104129	0.10155	0.102344	0.01271		
STD DEV	0.01118	0.009879	0.008995	0.018982	0.01029				

TABLE 2: ALLOY M, LUBRICANT NO. 2

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.108455	0.100589	0.088952	0.091787	0.106455	0.110084				
0.110084	0.110064	0.095146	0.095146	0.110084					
0.118515	0.115489	0.10237	0.10237	0.113471	RUN-IN	0.107783	0.008789		
0.115483	0.11475	0.10155	0.105217	0.113284					
0.120102	0.116166	0.107168	0.115042	0.118978	XXXXXXXXXXXXXX				
0.103522	0.088852	0.077109	0.088852	0.100589					
0.099622	0.095146	0.083204	0.096638	0.095146					
0.106408	0.10237	0.095304	0.107417	0.109435	DESIGN	0.100858	0.008339	2.688949	1.128956
0.105951	0.105217	0.096353	0.108151	0.110351					
0.108855	0.111105	0.100832	0.110543	0.114479	XXXXXXXXXXXXXX				
0.091787	0.103522	0.094721	0.097655	0.094721					
0.08619	0.107081	0.105589	0.096638	0.101114	USED STUD RUN-IN				
0.093284	0.116497	0.110444	0.098932	0.106408					
0.091766	0.120615	0.110351	0.100082	0.105217					
0.098483	0.127971	0.111105	0.104355	0.1111687	XXXXXXXXXXXXXX				
0.082981	0.094721	0.077109	0.098852	0.094721					
0.081711	0.104098	0.084697	0.092161	0.095146	USED STUD DESIGN				
0.088234	0.117506	0.096313	0.100352	0.10338					
0.086414	0.119882	0.097117	0.098616	0.103017					
0.090848	0.125723	0.100832	0.10548	0.10998	XXXXXXXXXXXXXX				
MEAN	0.099334	0.109868	0.098873	0.100184	0.105881				
STD DEV	0.011904	0.01058	0.010077	0.00716	0.00727				
					OVERALL				
					0.102415	0.010585			

TABLE 3: ALLOY M, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR VARIANCE	
							t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$
0.065359	0.062421	0.062421	0.059482	0.085359				
0.07275	0.059301	0.06229	0.083785	0.088288				
0.082173	0.061957	0.071057	0.074089	0.074089	RUN-IN	0.073697	0.011788	
0.086414	0.064228	0.083355	0.078788	0.078531				
0.100832	0.073145	0.096134	0.091435	0.088798	XXXXXXXXXXXXXXXXXXXX			
0.059482	0.053803	0.062421	0.058543	0.058603				
0.063785	0.054816	0.065279	0.059301	0.059301	XXXXXXXXXXXXXXXXXXXX			
0.066002	0.05934	0.071057	0.059934	0.068035	DESIGN	0.084786	0.008257	
0.06193	0.082695	0.071188	0.059833	0.07494			YES	
0.066407	0.070695	0.085561	0.068857	0.08321	XXXXXXXXXXXXXXXXXXXX			
0.056543	0.056543	0.068297	0.059482	0.083359				
0.060796	0.060796	0.063785	0.057806	0.06229	USED STUD RUN-IN			
0.064991	0.066002	0.068024	0.057912	0.065002		0.064988	0.006282	
0.064992	0.064992	0.071115	0.057336	0.065757				
0.079096	0.071307	0.079096	0.062731	0.073145	XXXXXXXXXXXXXXXXXXXX			
0.050663	0.047723	0.056663	0.058543	0.058543				
0.057806	0.050331	0.053321	0.051826	0.057806	USED STUD DESIGN			
0.066002	0.055889	0.057912	0.050983	0.055889		0.057177	0.006389	
0.064226	0.057338	0.06193	0.051975	0.051975	OVERALL			
0.071307	0.065957	0.071307	0.054765	0.060893	XXXXXXXXXXXXXXXXXXXX			
MEAN	0.088078	0.089883	0.072118	0.081682	0.08634		0.065159	0.010211
STD DEV	0.01156	0.008727	0.009895	0.009917	0.009457			

TABLE 4: ALLOY M, LUBRICANT NO. 4

	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE 95% Conf
0.1504	0.144545	0.1504	0.1504	0.156252	0.154758	0.154758	0.009805			
0.139869	0.147314	0.144338	0.141358	0.147222	0.15979	RUN-IN	0.150475			
0.143354	0.150123	0.152057	0.144362	0.140853	0.157689					
0.136642	0.145765	0.144362	0.144362	0.164031	0.176907	XXXXXXXXXXXXXX				
0.137963	0.171055	0.154442	0.154442	0.162103	0.1738					
0.132832	0.141618	0.159178	0.162103	0.154758	0.154758					
0.124971	0.133911	0.145825	0.153268	0.162689	0.162689	DESIGN	0.152599	0.014072	-0.61705	2.018427
0.13755	0.148189	0.153023	0.156889	0.156288	0.156987					
0.137344	0.115063	0.156987	0.156288	0.168145	0.172226	XXXXXXXXXXXXXX				
0.137983	0.159285	0.177492	0.175737	0.175737	0.175737					
0.1504	0.156252	0.162103	0.153328	0.168145	0.168145	USED STUD RUN-IN				
0.141358	0.153268	0.160708	0.168145	0.168145	0.168145					
0.152057	0.161722	0.168554	0.171779	0.171779	0.171779					
0.145063	0.155585	0.161896	0.170292	0.166102	0.166102					
0.163445	0.172811	0.156838	0.178682	0.185097	0.185097	XXXXXXXXXXXXXX				
0.153326	0.165028	0.1738	0.194255	0.1176724	0.1176724					
0.154756	0.165171	0.169633	0.185985	0.1177067	0.1177067	USED STUD DESIGN				
0.161722	0.177179	0.17235	0.178144	0.190372	0.190372					
0.156987	0.169204	0.168905	0.173719	0.183998	0.183998					
0.183342	0.190384	0.188606	0.202319	0.198353	0.198353	XXXXXXXXXXXXXX				
MEAN	0.147067	0.157574	0.1564	0.168509	0.171183	OVERALL	0.160659	0.015836		
STD DEV	0.01317	0.013902	0.008903	0.016978	0.012621					

DESIGN VS RUN-IN

DESIGN

DESIGN VS USED STUD DESIGN  
 USED STUD RUN-IN  
 OVERALL

DESIGN VS RUN-IN

DESIGN

DESIGN VS USED STUD DESIGN  
 USED STUD RUN-IN  
 OVERALL

TABLE 5: ALLOY M, LUBRICANT NO. 5

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR VARIANCE
MEAN	STD DEV						
0.085917	0.085917	0.091787	0.118182	0.100589			
0.093653	0.092161	0.093653	0.114537	0.098146			
0.105398	0.101361	0.101361	0.118515	0.098332	RUN-IN	0.102636	0.010448
0.105951	0.096353	0.102283	0.11695	0.098349			
0.113917	0.101419	0.106805	0.125723	0.100832	XXXXXXXXXXXXXX		
0.085917	0.077109	0.071235	0.100589	0.074172			
0.087683	0.078724	0.078724	0.093653	0.077231			
0.099342	0.082173	0.084194	0.098342	0.085204	DESIGN	0.08758	0.009691
0.097881	0.081825	0.081825	0.098349	0.083555			
0.100832	0.088498	0.088498	0.107168	0.089086	XXXXXXXXXXXXXX		
0.080045	0.080045	0.071235	0.109387	0.080045			
0.078724	0.084697	0.066774	0.102608	0.080218	USED STUD RUN-IN		
0.084194	0.088214	0.086824	0.107417	0.086214			
0.084884	0.084884	0.084884	0.108884	0.081825			
0.085086	0.085086	0.067632	0.114479	0.085581	XXXXXXXXXXXXXX		
0.082981	0.080045	0.074172	0.097655	0.080045			
0.073724	0.077231	0.07275	0.093653	0.077231	USED STUD DESIGN	1	F
0.089244	0.082173	0.077121	0.092274	0.082173			
0.088708	0.094112	0.074175	0.086414	0.08106			
0.090848	0.088498	0.076745	0.088498	0.080859	XXXXXXXXXXXXXX		
MEAN	0.091196	0.088605	0.082467	0.104784	0.085926	0.089707	0.012798
STD DEV	0.009787	0.007118	0.013947	0.011082	0.008414		

TABLE 6; ALLOY M, LUBRICANT NO.6

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST	F-TEST	TEST FOR MEAN	TEST FOR VARIANCE
0.077109	0.091787	0.077109	0.085917	0.094721						
0.075737	0.093853	0.08819	0.105589	0.09813						
0.079142	0.10237	0.093284	0.121541	0.105398	RUN-IN	0.097201	0.014951			
0.082569	0.100082	0.094059	0.125745	0.108884						
0.088148	0.104355	0.100245	0.131805	0.110543	XXXXXXXXXXXXXX					
0.065359	0.091787	0.085917	0.10589	0.088852						
0.062229	0.084697	0.083204	0.099622	0.075737						
0.086946	0.088234	0.087224	0.10338	0.079142	DESIGN	0.084523	0.014977			
0.058102	0.084884	0.088414	0.108151	0.079531						
0.059667	0.089673	0.089673	0.115604	0.084385	XXXXXXXXXXXXXX					
0.065297	0.100589	0.085917	0.097655	0.082981						
0.062279	0.095146	0.080218	0.09813	0.077231	USED STUD RUN-IN					
0.068024	0.092274	0.089244	0.098352	0.082173						
0.068819	0.090237	0.093295	0.096353	0.078786						
0.076745	0.091435	0.104355	0.103181	0.084385	XXXXXXXXXXXXXX					
0.074172	0.080045	0.077109	0.085917	0.085917						
0.063385	0.080218	0.07275	0.081711	0.077231	USED STUD DESIGN					
0.062968	0.078131	0.0751	0.092274	0.073078						
0.061164	0.072945	0.078001	0.091786	0.069584						
0.063957	0.077321	0.087911	0.096722	0.073757	XXXXXXXXXXXXXX					
MEAN	0.069015	0.089508	0.088909	0.102004	0.085411					
STD DEV	0.003189	0.008771	0.007141	0.013223	0.011802					
					OVERALL					
						0.08646	0.014608			

TABLE 7: ALLOY M, LUBRICANT NO. 7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST	F-TEST	TEST FOR VARIANCE
MEAN	STD DEV	MEAN	STD DEV	MEAN	STD DEV	MEAN	t*-1.68	F*-1.98	95% Conf
0.15326	0.135761	0.147473	0.147473	0.153326	0.153326	0.153326			
0.150291	0.144336	0.154756	0.138379	0.145825	0.145825	0.145825			
0.163655	0.156889	0.16752	0.147222	0.15109	RUN-IN	0.153698	0.0109		
0.161896	0.161194	0.147168	0.147168	0.150875	0.150875	0.150875			
0.183342	0.177492	0.156398	0.148401	0.151147	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.170877	0.159178	0.162103	0.159178	0.1504	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.154756	0.15922	0.157732	0.147314	0.150291	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.165588	0.168486	0.160756	0.153023	0.15109	DESIGN	0.153773	0.003808	-2.16742	1.531555
0.159091	0.170292	0.155685	0.155685	0.147168	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX	YES	YES	
0.172811	0.177492	0.176322	0.158834	0.151147	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.1738	0.167953	0.162103	0.1504	0.156252	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.153288	0.157732	0.157732	0.148802	0.154756	USED STUD RUN:IN	XXXXXXXXXXXXXXXXXXXXXX			
0.155593	0.165588	0.160756	0.154957	0.158823	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX	0.158882	0.008711	
0.154182	0.163999	0.15278	0.147168	0.151377	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.154442	0.166373	0.1495	0.14895	0.154442	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.159178	0.165028	0.156252	0.147473	0.1604	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
0.148802	0.157732	0.150291	0.150291	0.145825	USED STUD DESIGN	XXXXXXXXXXXXXXXXXXXXXX			
0.15399	0.15979	0.150123	0.153023	0.154957	0.153145	0.005955	-3.11687	2.187584	
0.150675	0.159792	0.145765	0.145765	0.151377	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX	YES	YES	
0.166958	0.159383	0.14895	0.147303	0.1495	XXXXXXXXXXXXXXXXXXXXXX	XXXXXXXXXXXXXXXXXXXXXX			
MEAN	0.160343	0.161685	0.157928	0.149835	0.151493	0.155874	0.00862		
STD DEV	0.009333	0.009639	0.007658	0.004984	0.00327				

TABLE 8; ALLOY M, LUBRICANT NO. 8

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR VARIANCE
						t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$
						95% Conf	
0.094721	0.094721	0.091787	0.103455	0.089852			
0.096622	0.095146	0.092161	0.104098	0.092161			
0.106408	0.104389	0.098332	0.110444	0.097323	RUN-IN	0.102214	0.00766
0.108151	0.106684	0.100816	0.108151	0.100082			
0.111479	0.114479	0.11223	0.11223	0.101419	XXXXXXXXXXXXXX		
0.089852	0.091787	0.085917	0.085917	0.077109			
0.089176	0.093653	0.092161	0.092161	0.083204			
0.095304	0.10237	0.101361	0.096313	0.090254	DESIGN	0.094276	0.008149
0.092231	0.105951	0.105217	0.092531	0.087943			
0.097309	0.111667	0.108293	0.097896	0.092023	XXXXXXXXXXXXXX		
0.091787	0.091787	0.088652	0.091787	0.080445			
0.089176	0.087683	0.093653	0.093653	0.087683	USED STUD RUN-IN		
0.096313	0.104389	0.107417	0.096313	0.097323			
0.096353	0.105951	0.111084	0.097117	0.098615			
0.102006	0.112792	0.116729	0.096722	0.101419	XXXXXXXXXXXXXX		
0.074172	0.080045	0.077109	0.085917	0.077109			
0.081711	0.087683	0.084697	0.089176	0.086119	USED STUD DESIGN		
0.097323	0.10237	0.093284	0.101361	0.098332			
0.100082	0.103017	0.099349	0.10155	0.100082			
0.102594	0.110543	0.106043	0.104355	0.102006	XXXXXXXXXXXXXX		
MEAN	0.095903	0.100355	0.100401	0.098207	0.091959	OVERALL	0.00931
STD DEV	0.009082	0.009516	0.009485	0.007719	0.008254		0.00935

DESIGN VS RUN-IN

t F  
3.548844 1.131799

YES NO

USED STUD RUN-IN

t F  
0.097466 0.008699

NO NO

DESIGN VS USED STUD DESIGN

t F  
-0.16255 1.6559295

NO NO

TABLE 9; ALLOY M, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST t* = 1.68	F-TEST F* = 1.98	TEST FOR VARIANCE 95% Conf
0.077109	0.071295	0.085917	0.085917	0.082981					
0.081711	0.069762	0.083204	0.08619	0.08619					
0.097323	0.078131	0.091264	0.094294	0.096313	RUN-IN	0.08731	0.008625		
0.096353	0.077236	0.088708	0.092531	0.095588					
0.100832	0.079684	0.090848	0.096722	0.096722	XXXXXXXXXXXXXXXXXXXX				
0.088852	0.071235	0.074172	0.077109	0.088652					
0.089176	0.063785	0.071256	0.084697	0.090668					
0.101361	0.069035	0.078131	0.091264	0.10826	DESIGN	0.087062	0.013904		
0.103017	0.065757	0.082559	0.093295	0.105217					
0.108293	0.074982	0.089673	0.099658	0.108043	XXXXXXXXXXXXXXXXXXXX				
0.074172	0.082981	0.068297	0.085917	0.074172					
0.07275	0.065279	0.075737	0.084697	0.093653	USED STUD RUN-IN				
0.080152	0.069035	0.081163	0.103938	0.116497					
0.078766	0.074175	0.082559	0.115483	0.108884					
0.081447	0.082522	0.090548	0.127971	0.108293	XXXXXXXXXXXXXXXXXXXX				
0.077109	0.082981	0.071235	0.091787	0.085917	USED STUD DESIGN				
0.078724	0.075737	0.071258	0.089176	0.08619					
0.086214	0.084194	0.069035	0.107417	0.091264					
0.084894	0.079531	0.063461	0.111084	0.088708					
0.090548	0.084385	0.065794	0.118415	0.092023	XXXXXXXXXXXXXXXXXXXX				
MEAN	0.087455	0.075088	0.082293	0.09885	OVERALL	0.086656	0.013305		
STD DEV	0.01059	0.006685	0.007473	0.013253					

DESIGN VS RUN-IN

F

NO YES

0.076033 2.598535

YES

USED STUD RUN-IN

F

0.087158 0.016867

NO

0.013215 -0.5127 1.106859

NO NO

USED STUD DESIGN

F

0.085095 0.013215 -0.5127 1.106859

NO NO

XXXXXXXXXXXXXXXXXXXX

F

0.088708 0.092023 XXXXXXXXXXXXXXXXXXXX

NO NO

TABLE 10; ALLOY M, LUBRICANT 10

				VALUE	DEVIATION	F-TEST	
						t-TEST	
0.097655	0.080045	0.082981	0.091787	0.085917		$t^* = 1.68$	95% Conf
0.090668	0.083204	0.083204	0.092161	0.081711		$F^* = 1.98$	
0.086234	0.086214	0.085204	0.106408	0.08183	RUN-IN	0.088	0.008626
0.084884	0.08412	0.080295	0.106684	0.080295			
0.086736	0.085581	0.081447	0.110543	0.080859	XXXXXXXXXXXXXX		
0.085917	0.085917	0.074172	0.080045	0.074172			
0.077231	0.075737	0.080218	0.080218	0.074243			
0.078131	0.071057	0.077121	0.083183	0.078131	DESIGN	0.075242	0.006183
0.071115	0.065757	0.068053	0.08295	0.069584			
0.068857	0.06702	0.068407	0.081447	0.06702	XXXXXXXXXXXXXX		
0.088852	0.077109	0.074172	0.080045	0.077109			
0.089762	0.07275	0.075737	0.077231	0.075737	USED STUD RUN-IN		
0.066002	0.072067	0.07611	0.077121	0.072067			
0.059633	0.069584	0.069584	0.07188	0.063461			
0.056603	0.069497	0.070082	0.072332	0.06334	XXXXXXXXXXXXXX		
0.074172	0.071235	0.074172	0.077109	0.077109			
0.072725	0.072725	0.075737	0.077231	0.074243	USED STUD DESIGN	$t$	
0.069035	0.07611	0.0751	0.079142	0.071057		-2.38675	1.483318
0.060399	0.069584	0.068819	0.069584	0.068819		YES	NO
0.058442	0.068857	0.068245	0.071307	0.064569	XXXXXXXXXXXXXX		
MEAN	0.075254	0.075207	0.076319	0.083298	0.074132		0.009502
STD DEV	0.012049	0.006737	0.005911	0.012058	0.006662		0.076647

## **ATTACHMENT III**

### **Phase I - Coefficient of Friction Dataset**

#### **AISI 4140 Phosphate Coated**

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1; ALLOY P,  
 LUBRICANT NO. 1  
 STUD1 STUD2 STUD3 STUD4 STUD5

	MEAN	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.109049	0.100684	0.100684	0.095072	0.095072
0.105552	0.099959	0.101383	0.097112	0.092842
0.103715	0.097933	0.105642	0.097933	0.096005
0.101038	0.094737	0.103838	0.096837	0.094038
0.100583	0.094827	0.103897	0.097422	0.094068
0.083984	0.081086	0.083884	0.081086	0.07549
0.094255	0.089994	0.099959	0.091418	0.082873
0.101798	0.091185	0.105642	0.094077	0.086364
0.101038	0.091906	0.106638	0.096837	0.087529
0.100147	0.091831	0.104968	0.097422	0.088475
0.083884	0.081086	0.083884	0.086682	0.083884
0.087146	0.089994	0.097112	0.091418	0.084297
0.088292	0.089257	0.101788	0.090221	0.086364
0.088988	0.088258	0.103138	0.089718	0.088069
0.089035	0.087916	0.102826	0.089594	0.088441
0.072691	0.069891	0.081086	0.07549	0.067092
0.078599	0.081448	0.089994	0.081448	0.086024
0.083471	0.084435	0.098897	0.087328	0.086577
0.087529	0.086069	0.098638	0.090447	0.079501
0.089035	0.087357	0.101764	0.09239	0.089085
MEAN	0.092496	0.088982	0.100351	0.096998
STD DEV	0.009884	0.007273	0.00713	0.006203

DESIGN VS RUN-IN  
 DESIGN  
 YES

USED STUD RUN-IN  
 USED STUD DESIGN  
 YES

OVERALL

YES

NO

YES

NO

YES

NO

TABLE 2: ALLOY P, LUBRICANT NO.2

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.90$	TEST FOR MEAN VARIANCE
0.095072	0.097688	0.086682	0.097666	0.095072	0.094205	0.004539			
0.099959	0.097112	0.086994	0.098536	0.094205	0.094077	0.004539			
0.101788	0.098605	0.091185	0.102751	0.101038	0.091177	0.004539			
0.098938	0.094036	0.089718	0.101038	0.098475	0.098475	0.004539			
0.100147	0.08239	0.089594	0.099612	0.098475	0.098475	0.004539			
0.072281	0.078288	0.078288	0.083684	0.072281	0.072281	0.004539			
0.080024	0.081446	0.082873	0.091416	0.078599	0.083471	0.005348	0.003918	0.003918	
0.089257	0.085399	0.086394	0.090969	0.08315	0.08315	0.005348	0.003918	0.003918	
0.091177	0.08534	0.087529	0.098337	0.08315	0.08315	0.005348	0.003918	0.003918	
0.092949	0.085679	0.086239	0.090076	0.084001	0.084001	0.005348	0.003918	0.003918	
0.081086	0.083384	0.075449	0.086682	0.08315	0.08315	0.005348	0.003918	0.003918	
0.085722	0.085722	0.084297	0.089994	0.08315	0.08315	0.005348	0.003918	0.003918	
0.094077	0.089237	0.086394	0.086897	0.08315	0.08315	0.005348	0.003918	0.003918	
0.095437	0.088258	0.089718	0.086137	0.08315	0.08315	0.005348	0.003918	0.003918	
0.098076	0.0889035	0.086475	0.084627	0.08315	0.08315	0.005348	0.003918	0.003918	
0.058691	0.07549	0.064292	0.061068	0.072281	0.072281	0.005348	0.003918	0.003918	
0.0729	0.078599	0.076599	0.091416	0.080024	0.080024	0.005348	0.003918	0.003918	
0.081542	0.083471	0.081542	0.086005	0.084435	0.084435	0.005348	0.003918	0.003918	
0.08386	0.08534	0.08398	0.085437	0.08534	0.08534	0.005348	0.003918	0.003918	
0.08512	0.082882	0.084001	0.093568	0.085679	0.085679	0.005348	0.003918	0.003918	
MEAN	0.087977	0.088775	0.086187	0.094599	0.085932	0.005348	0.003918	0.003918	
STD DEV	0.011254	0.008284	0.00443	0.0056935	0.00639	0.005348	0.003918	0.003918	

DESIGN VS RUN-IN

<sup>t</sup>  
<sup>F</sup>

DESIGN VS USED STUD DESIGN

<sup>t</sup>  
<sup>F</sup>

USED STUD RUN-IN

<sup>t</sup>  
<sup>F</sup>

USED STUD DESIGN

<sup>t</sup>  
<sup>F</sup>

OVERALL

<sup>t</sup>  
<sup>F</sup>

TABLE 3; ALLOY P, LUBRICANT NO. 3

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.07549	0.072891	0.072891	0.081491	0.058891			t-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$ 95% Conf
0.067199	0.070049	0.067189	0.058844	0.057218				
0.063207	0.088138	0.062242	0.057114	0.054517	RUN-IN	0.006802		
0.059053	0.080814	0.059053	0.053938	0.052476				
0.05774	0.06949	0.055408	0.062408	0.060154	X000000000000000000XX			
0.044682	0.053068	0.041879	0.047484	0.039075				
0.050087	0.057216	0.050087	0.046906	0.032981				
0.049888	0.055483	0.045524	0.046779	0.045824	DESIGN	0.047638	0.005093	DESIGN VS RUN-IN
0.051014	0.053207	0.047326	0.046091	0.045897				
0.050738	0.051905	0.048987	0.047819	0.044901	X000000000000000000XX			
0.050286	0.061491	0.050286	0.050286	0.051086				
0.051513	0.058844	0.048886	0.054356	0.050610	USED STUD	RUN-IN		
0.052588	0.058538	0.046722	0.050654	0.048722				
0.050283	0.054669	0.048822	0.046822	0.04736				
0.048987	0.051905	0.04957	0.04957	0.046652	X000000000000000000XX			
0.044682	0.047484	0.061491	0.036272	0.039075				
0.047233	0.054386	0.061498	0.04438	0.042853	USED STUD DESIGN			
0.04679	0.05162	0.060311	0.04679	0.042825				
0.045897	0.060283	0.067891	0.04736	0.042973				
0.046652	0.050154	0.058573	0.047819	0.049149	X000000000000000000XX			
MEAN	0.05269	0.058889	0.053119	0.049814	OVERALL	0.052345	0.008387	
STD DEV	0.008051	0.006624	0.008545	0.006866		0.010286		

TABLE 4; ALLOY P, LUBRICANT NO. 4

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	T-TEST $t^* = 1.68$	F-TEST $F^* = 1.98$	TEST FOR VARIANCE
0.164866	0.160925	0.160925	0.153714	0.160925	0.155397	0.149718	0.147838	0.007672	
0.159858	0.162558	0.163977	0.149718	0.155397	0.142587	0.160876	0.147838	0.007672	
0.156416	0.149109	0.149955	0.142587	0.150876	0.137003	0.14303	0.147838	0.007672	
0.146377	0.144369	0.14303	0.137003	0.14303	0.131068	0.136982	0.136982	0.007672	
0.141531	0.144146	0.137346	0.131068	0.136982	0.131393	0.136982	0.136982	0.007672	
0.142556	0.131383	0.136975	0.134184	0.142556	0.128828	0.139776	0.139776	0.007672	
0.142816	0.132871	0.141196	0.128828	0.139776	0.127791	0.139776	0.139776	0.007672	
0.14257	0.133334	0.138976	0.127791	0.139776	0.124128	0.134993	0.135713	0.005858	
0.138342	0.132314	0.137003	0.124128	0.134993	0.1221	0.144689	0.139976	0.006696	
0.135224	0.134207	0.133964	0.1221	0.144689	0.1131393	0.136975	0.132671	0.142616	USED STUD RUN-IN
0.142556	0.131393	0.136975	0.1131393	0.136975	0.146877	0.132671	0.142616	0.139976	0.006696
0.149718	0.138354	0.146877	0.132671	0.142616	0.143483	0.13241	0.148109	0.139976	0.006696
0.150876	0.138976	0.143483	0.13241	0.148109	0.137072	0.130974	0.14236	0.139976	0.006696
0.147716	0.139882	0.143734	0.137072	0.130974	0.137946	0.127404	0.145715	0.007672	
0.149375	0.137346	0.137946	0.137946	0.127404	0.139750	0.131393	0.134184	0.007672	
0.142556	0.136975	0.139750	0.139750	0.131393	0.152558	0.135513	0.146206	0.007672	
0.161075	0.149718	0.149718	0.139750	0.146206	0.158416	0.134258	0.150976	0.147925	0.01082
0.166584	0.147186	0.158416	0.158416	0.150976	0.15374	0.132314	0.153071	0.01082	4.962935
0.160432	0.147047	0.15374	0.15374	0.153071	0.16206	0.151467	0.136823	0.167076	3.411694
									YES
									YES
									OVERALL
MEAN	0.150156	0.140888	0.141724	0.133863	0.148563	0.142888	0.009478		
STD DEV	0.009533	0.007125	0.008123	0.007627	0.007626				

DESIGN VS USED STUD DESIGN

NO

TABLE 5; ALLOY P, LUBRICANT NO. 6

TABLE 6: ALLOY P, LUBRICANT NO. 6

	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN VARIANCE
0.081086	0.100884	0.095072	0.095072	0.096072	0.096072			
0.085722	0.092842	0.091418	0.092842	0.092842	0.092842			
0.084435	0.090221	0.088282	0.089282	0.092149	0.088282	RUN-IN	0.08919	0.004788
0.080231	0.089718	0.087529	0.087529	0.087529	0.087529			
0.081763	0.087357	0.086798	0.086798	0.087916	0.087916			
0.087082	0.078288	0.081086	0.081086	0.081086	0.081086			
0.0729	0.081448	0.082873	0.082873	0.082873	0.082873			
0.071894	0.081642	0.085399	0.085399	0.085399	0.085399			
0.07074	0.080231	0.08315	0.08315	0.08461	0.08242			
0.07169	0.080085	0.084001	0.08512	0.081763	0.080085			
0.079288	0.083884	0.083884	0.083884	0.083884	0.083884			
0.077774	0.087146	0.087146	0.087146	0.077174	0.089994	USED STUD RUN-IN	0.073696	0.005128
0.079812	0.085399	0.086364	0.086364	0.086364	0.086364			
0.077311	0.08242	0.08534	0.08534	0.077311	0.08461			
0.077846	0.082982	0.08456	0.08456	0.077846	0.08512			
0.072691	0.07549	0.076286	0.076286	0.072691	0.072691			
0.071476	0.081448	0.085722	0.085722	0.076599	0.077174	USED STUD DESIGN	1	
0.074789	0.082506	0.086384	0.086384	0.079648	0.083471			
0.07283	0.08242	0.08534	0.08534	0.076581	0.08461			
0.074489	0.08512	0.085679	0.085679	0.077267	0.084001			
MEAN	0.076208	0.084556	0.086194	0.081867	0.084591	OVERALL	0.082885	0.008413
STD DEV	0.004938	0.008655	0.003527	0.006823	0.006096			

TABLE 7: ALLOY P, LUBRICANT NO. 7

STUD	STUD	STUD	STUD	MEAN	STD	TEST FOR MEAN	TEST FOR VARIANCE
STUD	STUD	STUD	STUD	VALUE	DEVIATION	t-TEST	F-TEST
0.114837	0.131393	0.117431	0.1114637	0.109049			
0.111343	0.121286	0.109497	0.112765	0.111343			
0.108532	0.1110459	0.104678	0.109496	0.108532	RUN-IN	0.108794	0.0074
0.105236	0.1098358	0.099638	0.103136	0.104536			
0.102229	0.1039897	0.0877422	0.100683	0.102229	X00000000000000000000		
0.100864	0.114637	0.103459	0.111843	0.106254			
0.102806	0.114188	0.104229	0.107075	0.106497			
0.105642	0.119127	0.103715	0.109496	0.109496	DESIGN	0.10726	0.00476
0.108037	0.113635	0.101036	0.101036	0.109037		NO	YES
0.104433	0.110323	0.102229	0.104433	0.10711	X00000000000000000000		
0.111843	0.128801	0.123017	0.111843	0.111843			
0.111343	0.124142	0.114188	0.107075	0.111343	USED STUD RUN-IN		
0.115275	0.1222015	0.109496	0.109715	0.112385		0.1111957	0.009896
0.110837	0.115734	0.108836	0.109836	0.100737			
0.108181	0.111193	0.108576	0.100983	0.107646	X00000000000000000000		
0.114637	0.114637	0.128801	0.100984	0.111843			
0.111343	0.11561	0.111343	0.102806	0.111343	USED STUD DESIGN		
0.113348	0.117201	0.110459	0.108905	0.110459		0.111977	0.005596
0.115734	0.117833	0.110137	0.108636	0.110137			
0.11193	0.118353	0.108717	0.106576	0.112455	X00000000000000000000		
MEAN	0.109405	0.116583	0.108921	0.106292	0.109167	0.108997	0.008433
STD DEV	0.004596	0.008761	0.006894	0.004326	0.0027		

DESIGN VS RUN-IN

DESIGN VS USED STUD DESIGN

OVERALL

DESIGN VS USED STUD DESIGN

OVER

TABLE 8; ALLOY P, LUBRICANT NO.8

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	t-TEST $t^* = 1.68$	F-TEST $F^* = 1.93$	TEST FOR VARIANCE 95% Conf
0.092276	0.088682	0.088479	0.088684	0.088072					
0.084287	0.084287	0.088894	0.084297	0.088689					
0.083471	0.084435	0.088282	0.087328	0.088005	RUN-IN	0.087766	0.004307		
0.083388	0.083388	0.087529	0.088089	0.084737					
0.082862	0.084458	0.085112	0.086798	0.082949	X000000000000000000X				
0.081086	0.079288	0.083884	0.081086	0.081086					
0.088557	0.082873	0.085722	0.088994	0.088557					
0.087328	0.088282	0.089257	0.095041	0.090005	DESIGN	0.088889	0.005334	-0.38931	1.533241
0.089718	0.080447	0.087529	0.094038	0.098137					
0.092339	0.092949	0.082849	0.095186	0.098304	X000000000000000000X				
0.097888	0.089479	0.089479	0.083884	0.083884					
0.094285	0.088894	0.087146	0.087146	0.082842	USED STUD RUN-IN				
0.091185	0.080221	0.080221	0.089257	0.089897					
0.089718	0.081177	0.089718	0.089258	0.100338					
0.091272	0.084627	0.091831	0.089035	0.100147	X000000000000000000X				
0.100684	0.081086	0.081086	0.081086	0.072991					
0.084265	0.088557	0.082873	0.081448	0.087146	USED STUD DESIGN				
0.093113	0.080221	0.084435	0.080221	0.083113					
0.093336	0.084036	0.080447	0.095437	0.095437					
0.097981	0.088745	0.082389	0.086745	0.099812	X000000000000000000X				
MEAN	0.090478	0.088093	0.088543	0.088282	OVERALL				
STD DEV	0.005419	0.004716	0.002463	0.004697	0.005439				
					0.089527	0.005439			

TABLE 9: ALLOY P, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD DEVIATION	TEST FOR VARIANCE	
							t-TEST	F-TEST
0.097668	0.100664	0.089394	0.109049	0.089479	0.089994		<sup>t</sup> =1.68	<sup>F</sup> =1.96
0.108497	0.108497	0.078399	0.124112	0.089994				
0.1113348	0.113246	0.080377	0.131486	0.097933	RUN-IN	0.108612	0.018168	95% Conf
0.117133	0.116734	0.079501	0.134983	0.096837				
0.12317	0.124775	0.080344	0.138916	0.101219	X000000000000000000X			
0.109049	0.089479	0.081086	0.117431	0.086882				
0.111661	0.092342	0.075375	0.126985	0.08857			<sup>t</sup>	<sup>F</sup>
0.122978	0.098897	0.074789	0.124903	0.090221	DESIGN	0.102122	0.020334	0.633843 1.252716
0.131644	0.105238	0.073988	0.124827	0.087529			NO	NO
0.136777	0.109788	0.073397	0.129357	0.086594	X000000000000000000X			
0.085072	0.072691	0.072691	0.083394	0.089891				
0.111343	0.084287	0.089824	0.097112	0.07675	USED STUD RUN-IN			
0.116238	0.084077	0.087088	0.098897	0.079012			0.008899	0.0117278
0.112936	0.086137	0.067088	0.083338	0.081691				
0.127928	0.098883	0.089239	0.108717	0.08456	X000000000000000000X			
0.103459	0.092276	0.076288	0.088882	0.081086				
0.105852	0.0988536	0.082873	0.097112	0.085722	USED STUD DESIGN		<sup>t</sup>	<sup>F</sup>
0.107569	0.088897	0.079612	0.102751	0.084435			0.011151	3.325182
0.108037	0.097638	0.081491	0.108037	0.089718			NO	YES
0.1110859	0.095186	0.078406	0.113536	0.092949	X000000000000000000X			
					OVERALL			
MEAN	0.113708	0.089298	0.076038	0.112458	0.087174			
STD DEV	0.010537	0.011546	0.00557	0.01636	0.007423		0.08779	0.018038

TABLE 10; ALLOY P, LUBRICANT 10  
 STUD1 STUD2 STUD3 STUD4 STUD5

	MEAN VALUE	STD DEVIATION	t-TEST	F-TEST	TEST FOR VARIANCE
STUD1	0.083026	0.006299			
STUD2	0.086882	0.004529			
STUD3	0.081448	0.004547			
STUD4	0.079912	0.0045364			
STUD5	0.078041	0.004534			
	0.092276	0.086982	0.117431	0.069479	
	0.091418	0.081448	0.086994	0.101383	0.069994
	0.090221	0.079912	0.0845364	0.092149	0.091185 RUN-IN
	0.090447	0.078041	0.08334	0.086799	0.090447
	0.094627	0.077846	0.08512	0.084001	0.080713 XXXXXXXXXXXXXXXXX DESIGN VS RUN-IN
	0.081086	0.072891	0.083884	0.085072	0.081096 F
	0.084287	0.081448	0.078599	0.065722	0.084297
	0.084435	0.082506	0.081542	0.083471	0.087328 DESIGN YES
	0.086799	0.080231	0.08212	0.079501	0.086998 3.144089
	0.086238	0.080085	0.083441	0.078525	0.081086 3.068247
	0.078288	0.069891	0.07649	0.081086	0.081086 YES
	0.080024	0.074325	0.077174	0.078599	0.080024 USED STUD RUN-IN
	0.079812	0.077683	0.080577	0.078648	0.084435 0.003413
	0.075851	0.075121	0.075851	0.076121	0.08315
	0.075608	0.073929	0.075608	0.07281	0.081204 XXXXXXXXXXXXXXXXX DESIGN VS USED STUD DESIGN
	0.072691	0.067092	0.072691	0.07549	0.069891 F
	0.080024	0.076599	0.07576	0.069024	0.081448 USED STUD DESIGN
	0.079812	0.069577	0.079812	0.083471	0.086364 0.004577 -3.8519
	0.080231	0.078771	0.078041	0.080981	0.08534 1.024834 NO
	0.076727	0.076727	0.076525	0.077846	0.08512 XXXXXXXXXXXXXXXXX OVERALL
MEAN	0.083026	0.077685	0.081872	0.084455	0.085171 0.00703
STD DEV	0.006299	0.004529	0.004547	0.010417	0.005281
					0.0822 0.00703

## ATTACHMENT IV

### Phase I - Coefficient of Friction Dataset

#### AISI 4140 Alloy Steel (B7)

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every AISI 4140 stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

TABLE 1; ALLOY A, LUBRICANT NO.1

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.114637	0.114637	ERR	ERR	ERR	ERR	ERR	t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$ 95% Confidence
0.118454	0.118454	ERR	ERR	ERR	ERR	ERR		
0.115275	0.121052	ERR	ERR	ERR	ERR	ERR		
0.110837	0.120631	ERR	ERR	ERR	ERR	ERR		
0.109252	0.120494	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX	DESIGN VS RUN-IN		
0.089479	0.089479	ERR	ERR	ERR	ERR	ERR		
0.101383	0.095689	ERR	ERR	ERR	ERR	ERR		
0.100824	0.103715	ERR	ERR	ERR	DESIGN 0.100011	0.007379	t 6.115088	F 3.176385
0.099638	0.109437	ERR	ERR	ERR	ERR	ERR	Yes	No
0.09854	0.111193	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX	DESIGN VS RUN-IN		
0.108049	0.109049	ERR	ERR	ERR	ERR	ERR		
0.108497	0.109932	ERR	ERR	ERR	USED STUD RUN-IN	0.107416	0.002308	DESIGN VS USED STUD DESIGN
0.1110459	0.106605	ERR	ERR	ERR	ERR	ERR		
0.105938	0.105238	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX	DESIGN VS USED STUD DESIGN		
0.103361	0.106039	ERR	ERR	ERR	USED STUD DESIGN	0.095808	0.004286	t -1.555939
0.089479	0.089479	ERR	ERR	ERR	ERR	ERR	No	F 2.991219
0.092842	0.097112	ERR	ERR	ERR	XXXXXXXXXXXXXXXXXXXXXX	OVERALL	No	
0.095041	0.098897	ERR	ERR	ERR	ERR	ERR		
0.096137	0.101038	ERR	ERR	ERR	ERR	ERR		
0.096304	0.101754	ERR	ERR	ERR	ERR	ERR		
MEAN	0.103221	0.106533	ERR	ERR	ERR	0.104902	0.0092	
STD DEV	0.008638	0.009671	ERR	ERR	ERR			

STUD1	STUD2	STUD3	STUD4	STUD5	TEST FOR MEAN			TEST FOR VARIANCE		
					MEAN VALUE	STD DEVIATION	t-TEST t*=1.734	F-TEST F*=3.18	95% Confidence	
0.103459	0.089479	ERR	ERR	ERR						
0.104229	0.101383	ERR	ERR	ERR						
0.105642	0.098897	ERR	ERR	ERR						
0.103138	0.100398	ERR	ERR	ERR						
0.103661	0.101219	ERR	ERR	ERR						
0.089479	0.072691	ERR	ERR	ERR						
0.092842	0.08994	ERR	ERR	ERR						
0.09986	0.098897	ERR	ERR	ERR						
0.103638	0.102438	ERR	ERR	ERR						
0.106639	0.103361	ERR	ERR	ERR						
0.095072	0.072691	ERR	ERR	ERR						
0.099359	0.082873	ERR	ERR	ERR						
0.104678	0.089257	ERR	ERR	ERR						
0.102438	0.094036	ERR	ERR	ERR						
0.101754	0.096304	ERR	ERR	ERR						
0.081086	0.069891	ERR	ERR	ERR						
0.08994	0.082873	ERR	ERR	ERR						
0.093113	0.087328	ERR	ERR	ERR						
0.095437	0.092636	ERR	ERR	ERR						
0.09854	0.094068	ERR	ERR	ERR						
MEAN	0.098698	0.091033	ERR	ERR						
STD DEV	0.006671	0.010324	ERR	ERR						

TABLE 3: ALLOY A, LUBRICANT NO. 3

STUD 1	STUD 2	STUD 3	STUD 4	STUD 5	MEAN VALUE	STD DEVIATION	TEST FOR VARIANCE		
							t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$	95% Confidence
0.15929	0.156502	ERR	ERR	ERR	ERR	ERR			
0.161075	0.152558	ERR	ERR	ERR	ERR	ERR			
0.157339	0.151801	ERR	ERR	ERR	ERR	ERR			
0.151063	0.146377	ERR	ERR	ERR	ERR	ERR			
0.145715	0.141008	ERR	ERR	ERR	ERR	ERR			
0.145346	0.142558	ERR	ERR	ERR	ERR	ERR			
0.151138	0.146877	ERR	ERR	ERR	ERR	ERR			
0.140723	0.141646	ERR	ERR	ERR	ERR	ERR			
0.139882	0.137672	ERR	ERR	ERR	ERR	ERR			
0.135777	0.131591	ERR	ERR	ERR	ERR	ERR			
0.150925	0.150925	ERR	ERR	ERR	ERR	ERR			
0.151138	0.156817	ERR	ERR	ERR	ERR	ERR			
0.150878	0.150978	ERR	ERR	ERR	ERR	ERR			
0.145038	0.145038	ERR	ERR	ERR	ERR	ERR			
0.141008	0.139962	ERR	ERR	ERR	ERR	ERR			
0.142556	0.156502	ERR	ERR	ERR	ERR	ERR			
0.148298	0.151138	ERR	ERR	ERR	ERR	ERR			
0.149032	0.154567	ERR	ERR	ERR	ERR	ERR			
0.145708	0.151063	ERR	ERR	ERR	ERR	ERR			
0.142577	0.146238	ERR	ERR	ERR	ERR	ERR			
MEAN	0.147715	0.147586	ERR	ERR	ERR	ERR			
STD DEV	0.008637	0.006915	ERR	ERR	ERR	ERR			

TABLE 6; ALLOY A, LUBRICANT NO.5

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN VARIANCE
0.100684	0.106254	ERR	ERR	ERR	0.101049	0.002971	
0.097112	0.104229	ERR	ERR	ERR			
0.097933	0.102751	ERR	ERR	ERR			
0.087588	0.101038	ERR	ERR	ERR			
0.100683	0.10229	ERR	ERR	ERR			
0.089479	0.092276	ERR	ERR	ERR			
0.08857	0.099959	ERR	ERR	ERR			
0.091185	0.103715	ERR	ERR	ERR			
0.089718	0.101738	ERR	ERR	ERR			
0.093508	0.103361	ERR	ERR	ERR			
0.083894	0.103459	ERR	ERR	ERR			
0.087146	0.104229	ERR	ERR	ERR			
0.088292	0.110459	ERR	ERR	ERR			
0.088988	0.108037	ERR	ERR	ERR			
0.090713	0.104433	ERR	ERR	ERR			
0.081086	0.081086	ERR	ERR	ERR			
0.080024	0.089994	ERR	ERR	ERR			
0.081542	0.094077	ERR	ERR	ERR			
0.081691	0.096137	ERR	ERR	ERR			
0.082882	0.09854	ERR	ERR	ERR			
MEAN	0.089632	0.100403	ERR	ERR	0.095018	0.008595	
STD DEV	0.006617	0.00684	ERR	ERR			

DESIGN VS RUN-IN  
<sup>t</sup>  
<sup>F</sup>

DESIGN VS USED STUD DESIGN  
<sup>t</sup>  
<sup>F</sup>

USED STUD RUN-IN  
<sup>t</sup>  
<sup>F</sup>

OVERALL  
<sup>t</sup>  
<sup>F</sup>

DESIGN VS USED STUD DESIGN  
<sup>t</sup>  
<sup>F</sup>

TABLE 6; ALLOY A6;		LUBRICANT NO. 6	FOR VARIANCE					
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN	STD	FOR MEAN	

TABLE 6; ALLOY A6, STUD1		LUBRICANT NO. 6	STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.100664	0.111843	ERR	ERR	ERR	ERR	ERR	ERR	0.110633	0.004473	t-TEST $t^*=1.734$	F-TEST $F^*=3.18$
0.107075	0.1114188	ERR	ERR	ERR	ERR	ERR	ERR				95% Confidence
0.113348	0.116238	ERR	ERR	ERR	ERR	ERR	ERR				
0.110837	0.113635	ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXX			
0.108181	0.110323	ERR	ERR	ERR	ERR	ERR	ERR				
0.089479	0.100664	ERR	ERR	ERR	ERR	ERR	ERR				
0.094265	0.105652	ERR	ERR	ERR	ERR	ERR	ERR				
0.100824	0.110459	ERR	ERR	ERR	ERR	ERR	ERR	DESIGN	0.103823	0.008319	2.280087
0.101738	0.115035	ERR	ERR	ERR	ERR	ERR	ERR				3.453908
0.104968	0.115142	ERR	ERR	ERR	ERR	ERR	ERR				
0.089479	0.103459	ERR	ERR	ERR	ERR	ERR	ERR				
0.095689	0.111343	ERR	ERR	ERR	ERR	ERR	ERR	USED STUD RUN-IN			
0.097933	0.110459	ERR	ERR	ERR	ERR	ERR	ERR		0.03042	0.007688	
0.098238	0.110137	ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXX			
0.102229	0.111394	ERR	ERR	ERR	ERR	ERR	ERR				
0.083884	0.100664	ERR	ERR	ERR	ERR	ERR	ERR	USED STUD DESIGN			
0.094265	0.104229	ERR	ERR	ERR	ERR	ERR	ERR		0.103285	0.010985	1.2348
0.097933	0.113348	ERR	ERR	ERR	ERR	ERR	ERR				1.736985
0.097538	0.1117133	ERR	ERR	ERR	ERR	ERR	ERR				No
0.104433	0.119424	ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXXXXXX			No
								OVERALL			
MEAN	0.098653	0.110738	ERR	ERR	ERR	ERR	ERR				
STD DEV	0.007424	0.005324	ERR	ERR	ERR	ERR	ERR				

TABLE 7, ALLOY A, LUBRICANT NO. 7

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE
0.134184	0.136975	ERR	ERR	ERR	0.124958	0.009434	t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$
0.131249	0.134092	ERR	ERR	ERR				95% Confidence
0.125866	0.126828	ERR	ERR	ERR				
0.119232	0.117633	ERR	ERR	ERR				
0.113536	0.109788	ERR	ERR	ERR				
0.128601	0.123017	ERR	ERR	ERR				
0.118454	0.119876	ERR	ERR	ERR				
0.118164	0.118164	ERR	ERR	ERR				
0.117833	0.116434	ERR	ERR	ERR				
0.115142	0.117818	ERR	ERR	ERR				
0.139766	0.128601	ERR	ERR	ERR				
0.132671	0.126985	ERR	ERR	ERR				
0.12894	0.128715	ERR	ERR	ERR				
0.122299	0.126225	ERR	ERR	ERR				
0.121103	0.121103	ERR	ERR	ERR				
0.128601	0.123017	ERR	ERR	ERR				
0.121298	0.118454	ERR	ERR	ERR				
0.122298	0.118164	ERR	ERR	ERR				
0.1233428	0.115734	ERR	ERR	ERR				
0.12424	0.118889	ERR	ERR	ERR				
MEAN	0.124112	0.122332	ERR	ERR				
STD DEV	0.00673	0.006635	ERR	ERR				
					OVERALL			
						0.123222	0.006658	

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR VARIANCE		
							t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$	95% Confidence
0.114637	0.089479	ERR	ERR	ERR	0.096523	0.008683			
0.095689	0.092842	ERR	ERR	ERR	0.096523	0.008683			
0.096005	0.094077	ERR	ERR	ERR	0.096523	0.008683			
0.096137	0.095437	ERR	ERR	ERR	0.096523	0.008683			
0.095186	0.095745	ERR	ERR	ERR	0.096523	0.008683			
0.089479	0.092276	ERR	ERR	ERR	0.096523	0.008683			
0.094265	0.092842	ERR	ERR	ERR	0.096523	0.008683			
0.096369	0.101788	ERR	ERR	ERR	0.096523	0.008683			
0.098238	0.103138	ERR	ERR	ERR	0.096523	0.008683			
0.096883	0.105504	ERR	ERR	ERR	0.096523	0.008683			
0.100684	0.095072	ERR	ERR	ERR	0.096523	0.008683			
0.097112	0.101383	ERR	ERR	ERR	0.096523	0.008683			
0.098897	0.101788	ERR	ERR	ERR	0.096523	0.008683			
0.097538	0.108037	ERR	ERR	ERR	0.096523	0.008683			
0.09854	0.105504	ERR	ERR	ERR	0.096523	0.008683			
0.095072	0.095072	ERR	ERR	ERR	0.096523	0.008683			
0.095689	0.097112	ERR	ERR	ERR	0.096523	0.008683			
0.101788	0.098897	ERR	ERR	ERR	0.096523	0.008683			
0.103138	0.101738	ERR	ERR	ERR	0.096523	0.008683			
0.103897	0.106575	ERR	ERR	ERR	0.096523	0.008683			
MEAN	0.09829	0.098715	ERR	ERR	0.098503	0.005181			
STD DEV	0.005044	0.005436	ERR	ERR					

TABLE 9: ALLOY A, LUBRICANT NO. 9

STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN VARIANCE
0.106254	0.109049	ERR	ERR	ERR	ERR	t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$ 95% Confidence
0.118454	0.118454	ERR	ERR	ERR	ERR		
0.12394	0.124903	ERR	ERR	ERR	ERR		
0.131644	0.130974	ERR	ERR	ERR	ERR		
0.132114	0.130544	ERR	ERR	ERR	ERR		
0.106254	0.111843	ERR	ERR	ERR	ERR		
0.104229	0.112765	ERR	ERR	ERR	ERR		
0.098897	0.114312	ERR	ERR	ERR	ERR		
0.099638	0.112236	ERR	ERR	ERR	ERR		
0.097422	0.110859	ERR	ERR	ERR	ERR		
0.089479	0.103459	ERR	ERR	ERR	ERR		
0.082873	0.104229	ERR	ERR	ERR	ERR		
0.079612	0.100824	ERR	ERR	ERR	ERR		
0.075851	0.101038	ERR	ERR	ERR	ERR		
0.075608	0.101754	ERR	ERR	ERR	ERR		
0.083884	0.089479	ERR	ERR	ERR	ERR		
0.080624	0.091418	ERR	ERR	ERR	ERR		
0.077683	0.094077	ERR	ERR	ERR	ERR		
0.073686	0.097538	ERR	ERR	ERR	ERR		
0.070571	0.102826	ERR	ERR	ERR	ERR		
MEAN	0.095405	0.108129	ERR	ERR	ERR	OVERALL 0.101767	0.01726
STD DEV	0.019658	0.011626	ERR	ERR	ERR		

DESIGN VS RUN-IN

<sup>t</sup> F

DESIGN

<sup>t</sup> No

DESIGN

<sup>t</sup> Yes

DESIGN

<sup>t</sup> No

TABLE 10: ALLOY A, LUBRICANT NO. 10

TABLE 10; ALLOY A, LUBRICANT NO. 10									
STUD1	STUD2	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST FOR MEAN	TEST FOR VARIANCE	
0.097868	0.092276	ERR	ERR	ERR	0.091591	0.003475	t-TEST $t^* = 1.734$	F-TEST $F^* = 3.18$	95% Confidence
0.091418	0.089594	ERR	ERR	ERR					
0.094077	0.090221	ERR	ERR	ERR					
0.093338	0.087529	ERR	ERR	ERR					
0.095508	0.085679	ERR	ERR	ERR					
0.089479	0.083884	ERR	ERR	ERR					
0.091418	0.085722	ERR	ERR	ERR					
0.094077	0.089257	ERR	ERR	ERR					
0.091177	0.083888	ERR	ERR	ERR					
0.089035	0.084001	ERR	ERR	ERR					
0.083884	0.083884	ERR	ERR	ERR					
0.084297	0.089994	ERR	ERR	ERR					
0.084435	0.093113	ERR	ERR	ERR					
0.083115	0.090447	ERR	ERR	ERR					
0.082322	0.088475	ERR	ERR	ERR					
0.083884	0.081086	ERR	ERR	ERR					
0.087146	0.082873	ERR	ERR	ERR					
0.085599	0.087328	ERR	ERR	ERR					
0.083888	0.08461	ERR	ERR	ERR					
0.079525	0.086238	ERR	ERR	ERR					
MEAN	0.088166	0.087025	ERR	ERR	0.087595	0.000425	OVERALL		
STD DEV	0.005019	0.003347	ERR	ERR					

## **Appendix C**

### **COEFFICIENT OF FRICTION DATA FOR THE PHASE II TEST ASSEMBLIES**

This appendix includes the calculated coefficient of friction data, based on the equation of Appendix A. The actual test information, i.e., the individual loads and corresponding torque values, can be obtained by requesting from the authors at:

Westinghouse Electric Company  
Plant Apparatus Division  
500 Penn Center Boulevard  
Pittsburgh, PA 15235-5713

## KEY TO APPENDIX C

Alloy Code	Page Number	Alloy Combination			Comments
		Stud	Nut	Washer	
A	App. B, 42	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AM	15, 33	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	Machined threads
P	App. B	AISI 4140, Mn Phosphate Coated	Carbon Steel, Gr 2H	Carbon Steel	Rolled threads
AR1	13, 31	AISI 4140	Carbon Steel, Gr 2H	Carbon Steel	1.5 inches
AZ	12, 30, 44	Steel, Grade 5, Zinc plated	Carbon Steel, Grade 5	Carbon Steel	Rolled threads
AS	16, 34	AISI 4340	AISI 4340	Type 430 Stainless Nutlock	Machined threads 1.0 inches
M	App. B	K-500	Monel 400	Carbon Steel	Rolled threads
MK	3, 21, 39	K-500	K-500	Carbon Steel	Rolled threads
MCU	6, 24	K-500	K-500	70-30 Cu-Ni	Rolled threads
MH	7, 25	K-500	K-500	HY 80	Rolled threads
MS	4, 22	K-500	K-500	Type 430	Rolled threads
MI	5, 23	K-500	K-500	Alloy 625	Rolled threads
MA	14, 32	K-500	Monel 400	Carbon Steel	Rolled threads 1.5 inches
I	App. B, 40	Alloy 625	Alloy 625	Carbon Steel	Rolled threads
ICR	8, 26, 41	Alloy 625, Chromium plated	Alloy 625	Carbon Steel	Rolled threads
II	9, 27	Alloy 625	Alloy 625	Alloy 625	Rolled threads
IMC2	18, 35	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 2
IMC3	17, 36	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads Class 3
IMA	19, 37	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 1.75 inches
IMB	20, 38	Alloy 625	Alloy 625	Alloy 625	Military Specification Machined threads 2.00 inches
T	11, 29, 43	Titanium, Gr 5	Alloy 625	Carbon Steel	Rolled threads
SS	10, 28	Type 17-4PH Stainless Steel	Type 316 stainless	Type 316 stainless	Rolled threads
SSC	10, 28	Type 17-4PH Stainless Steel	Type 316 stainless	Carbon Steel	Rolled threads

**Lubricant Key**

Data Set Number	Page Number	Lubricant Used
1 through 95	3 through 20	Molykote P37
96 through 190	21 through 38	RLGMO
191 through 220	39 through 44	Fel Pro N7000
Note: There were no Data Sets corresponding to Numbers 31 through 35 or 126 through 130.		

The main body of the following tables list each individual calculated coefficient of friction value, based on the equation of Appendix A, for every stud tested. The mean coefficient of friction and standard deviations for each individual stud is provided at the bottom of the table, while for alloy combinations that had at least four duplicate assemblies the mean coefficient of friction, standard deviation and the results of the statistical tests performed for all studs tested under the same loading sequence are provided to the right of the individual values.

**Authors Note:**

On the following pages, data columns which are marked as 'ERR' or '0.0000' signify that those assemblies were not tested. Markings of "ERR" or a blank entry within a column of data indicates that fewer than five load increments were used since higher loads would have exceeded the yield strength of at least one of the fastener assembly components, generally the washer or nut.

SET 1-5	Alloy Code MK					MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance
	STUD1	STUD2	STUD3	STUD4	STUD5					
0.1445	0.1283	0.1445	0.1413	0.1186						
0.1305	0.1223	0.1256	0.1191	0.1256						
0.1341	0.1242	0.1220	0.1165	0.1132	RUN-IN	0.1246	0.0092	t* = 1.68	F* = 1.98	0.1474
0.1266	0.1306	0.1185	0.1129	0.1137					= 0.505	0.1017
0.1229	0.1291	0.1166	0.1140	0.1185	XXXXXXXXXXXXXX					
0.1121	0.1089	0.1218	0.1186	0.1121						
0.1028	0.1126	0.1256	0.1207	0.1256						
0.1121	0.1242	0.1165	0.1231	0.1176	DESIGN	0.1184	0.0059	t	F	0.1329
0.1145	0.1242	0.1193	0.1210	0.1226				0.2046	2.4695	0.1038
0.1160	0.1260	0.1179	0.1197	0.1235	XXXXXXXXXXXXXX			No	Yes	
0.0894	0.1056	0.1089	0.1154	0.1089						
0.1012	0.1093	0.1110	0.1093	0.1028						
0.1033	0.1143	0.1110	0.1099	0.1099	CYCLE3	0.1114	0.0079	t	F	0.1308
0.1097	0.1234	0.1202	0.1089	0.1185				0.2534	0.5617	0.0920
0.1114	0.1254	0.1216	0.1160	0.1197				No	No	
MEAN	0.1154	0.1206	0.1201	0.1178	0.1167					
STD DEV	0.0143	0.0081	0.0084	0.0079	0.0065					

DATA SET 6.7		Alloy Code MS				
STUD1	STUD2	STUD3	STUD4	STUD5		
0.1380	0.1380	ERR	ERR	ERR	ERR	ERR
0.1419	0.1337	ERR	ERR	ERR	ERR	ERR
0.1462	0.1275	ERR	ERR	ERR	ERR	RUN-IN
0.1513	0.1268	ERR	ERR	ERR	ERR	ERR
0.1660	0.1372	ERR	ERR	ERR	ERR	XXXXXX
0.0959	0.0797	ERR	ERR	ERR	ERR	ERR
0.1044	0.0800	ERR	ERR	ERR	ERR	ERR
0.1143	0.0912	ERR	ERR	ERR	ERR	DESIGN
0.1266	0.1047	ERR	ERR	ERR	ERR	ERR
0.1310	0.1134	ERR	ERR	ERR	ERR	XXXXXX
0.1056	0.0894	ERR	ERR	ERR	ERR	ERR
0.0931	0.0996	ERR	ERR	ERR	ERR	ERR
0.1055	0.1011	ERR	ERR	ERR	ERR	CYCLE3
0.1145	0.1121	ERR	ERR	ERR	ERR	ERR
0.1222	0.1191	ERR	ERR	ERR	ERR	ERR
<b>Mean</b>	<b>0.1238</b>	<b>0.1102</b>	<b>ERR</b>	<b>ERR</b>	<b>ERR</b>	
<b>Std Dev</b>	<b>0.0217</b>	<b>0.0199</b>	<b>ERR</b>	<b>ERR</b>	<b>ERR</b>	

DATA SET 11.12 Alloy Code MI		STUD1	STUD2	STUD3	STUD4	STUD5
0.1413	0.1348	ERR	ERR	ERR	ERR	ERR
0.1305	0.1402	ERR	ERR	ERR	ERR	ERR
0.1363	0.1610	ERR	ERR	ERR	ERR	RUN-IN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXX
0.1121	0.1056	ERR	ERR	ERR	ERR	ERR
0.1110	0.1093	ERR	ERR	ERR	ERR	ERR
0.1220	0.1286	ERR	ERR	ERR	ERR	DESIGN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXXXXXX
0.1121	0.1024	ERR	ERR	ERR	ERR	ERR
0.1093	0.1028	ERR	ERR	ERR	ERR	ERR
0.1176	0.1154	ERR	ERR	ERR	ERR	CYCLE3
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	ERR
0.1214	0.1222	ERR	ERR	ERR	ERR	ERR
0.0119	0.0203	ERR	ERR	ERR	ERR	ERR
Mean						
Std Dev						

DATA SET 16-20		Alloy Code	MCU	STUD3	STUD4	STUD5	MEAN	STD	TEST for	TEST for
							VALUE	DEVIATION	Mean	Variance
STUD1	STUD2	0.1234	0.1684	0.1459	0.1234	0.1154	0.1145	RUN-IN	$t^*=1.68$	$F^*=1.98$
0.1218	0.1256	0.1186	0.1380	0.1186	0.1167	0.1145	RUN-IN	0.1310	0.0137	0.1649
0.1418	0.1210	0.1340	0.1402	0.1256	0.1223	0.1375	XXXXXXXXXXXXXX			0.0970
0.1575	0.1288	0.1453	0.1440	0.1375	0.1178	0.1008	XXXXXXXXXXXXXX			
0.1782										
ERR	0.1065	0.1121	0.1024	0.0829	0.1056	0.0972	DESIGN	0.1009	0.0103	$t$
ERR	0.0927	0.0863	0.0972	0.0820	0.0972	0.0931	0.1028	XXXXXXXXXXXXXX	0.6263	$F$
ERR	0.0963	0.1061	0.1061	0.1023	0.1062	0.1062	XXXXXXXXXXXXXX		No	0.1272
ERR	0.1088	0.1193	0.1065	0.0952	0.1121	0.0959	0.0972	CYCLE3	0.0925	$t$
ERR	0.1065	0.0862	0.0862	0.0829	0.0829	0.0798	0.0755	CYCLE3	0.0102	$F$
ERR	0.0820	0.0931	0.0865	0.0800	0.0947	0.0972	0.0984		No	0.1186
ERR	0.1049		0.0971	0.0893					No	0.0664
MEAN	0.1450	0.1067	0.1145	0.1019	0.1094					
STD DEV	0.0234	0.0180	0.0255	0.0221	0.0125					

DATA SET 21.22		Alloy Code	MH						
STUD1	STUD2	STUD3	STUD4	STUD5	ERR	ERR	ERR	ERR	ERR
0.1445	0.1413				ERR	ERR	ERR	ERR	ERR
0.1386	0.1402				ERR	ERR	ERR	ERR	ERR
0.1494	0.1473				ERR	ERR	ERR	ERR	ERR
0.1529	0.1498				ERR	ERR	ERR	ERR	ERR
0.1569	0.1539				ERR	ERR	ERR	ERR	ERR
0.1121	0.1154				ERR	ERR	ERR	ERR	ERR
0.1175	0.1175				ERR	ERR	ERR	ERR	ERR
0.1209	0.1275				ERR	ERR	ERR	ERR	ERR
0.1234	0.1330				ERR	ERR	ERR	ERR	ERR
0.1297	0.1378				ERR	ERR	ERR	ERR	ERR
0.1121	0.1089				ERR	ERR	ERR	ERR	ERR
0.1028	0.1044				ERR	ERR	ERR	ERR	ERR
0.1110	0.1121				ERR	ERR	ERR	ERR	ERR
0.1226	0.1226				ERR	ERR	ERR	ERR	ERR
0.1235	0.1247				ERR	ERR	ERR	ERR	ERR
Mean	0.1279	0.1291			ERR	ERR	ERR	ERR	ERR
Std Dev	0.0168	0.0157			ERR	ERR	ERR	ERR	ERR

DATA SET 26-30		Alloy Code ICR					90/95 Tolerance				
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance		
								95% Confidence			
0.1276	0.1276	0.1034	0.1082	0.1034				t= 1.68	F=1.98		
0.1083	0.1107	0.0889	0.0962	0.1011							
0.1119	0.1071	0.0876	0.0909	0.1006	RUN-IN	0.1052	0.0106				
0.1131	0.1070	0.0936	0.0948	0.1070							
0.1182	0.1112	0.1003	0.0973	0.1132	XXXXXXXXXXXXXX						
0.1131	0.1034	0.0986	0.0937	0.1034							
0.1083	0.0962	0.0889	0.0768	0.0962							
0.1055	0.0925	0.0909	0.0763	0.0974	DESIGN	0.0989	0.0114				
0.1119	0.0985	0.0972	0.0813	0.1034							
0.1231	0.1053	0.1073	0.0894	0.1142	XXXXXXXXXXXXXX						
0.1131	0.1179	0.1034	0.0840	0.1082							
0.1107	0.1035	0.0986	0.0720	0.0986							
0.0990	0.0974	0.1022	0.0714	0.1006	CYCLE3	0.1014	0.0127				
0.1107	0.1046	0.1021	0.0826	0.1046							
0.1221	0.1092	0.1142	0.0934	0.1112							
Mean	0.1130	0.1061	0.0985	0.0872	0.1042						
Std Dev	0.00072	0.0088	0.0075	0.0105	0.0056						

DATA SET 36-40		Alloy Code II				TEST for Variance				90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean			
0.1469	0.1373	0.1373	0.1276	0.1179							
0.1519	0.1470	0.1374	0.1422	0.1325							
0.1572	0.1556	0.1346	0.1556	0.1362	RUN-IN	0.1492	0.0145				
0.1632	0.1679	0.1498	0.1607	0.1449							
0.1700	0.1756	0.1567	0.1681	0.1557	XXXXXXXXXXXXXX						
0.1131	0.1179	0.1373	0.1082	0.1179							
0.1059	0.1035	0.1204	0.1083	0.1107							
0.1087	0.1071	0.1330	0.1168	0.1071	DESIGN	0.1156	0.0089				
0.1119	0.1095	0.1144	0.1217	0.1107							
0.1221	0.1191	0.1132	0.1348	0.1162	XXXXXXXXXXXXXX						
0.1082	0.1179	0.1082	0.1179	0.1082							
0.0986	0.0962	0.1011	0.0986	0.0962							
0.0974	0.1022	0.1071	0.1038	0.1006	CYCLE3	0.1067	0.0072				
0.1034	0.1021	0.1119	0.1119	0.1046							
0.1152	0.1132	0.1132	0.1201	0.1092							
Mean	0.1249	0.1248	0.1250	0.1264	0.1179						
Std Dev	0.0253	0.0256	0.0169	0.0215	0.0170						

DATA SET 41-45		Code SS		Studs 41-44 only		MEAN		STD		TEST for		TEST for	
STUD1	STUD2	STUD3	STUD4	STUD5		VALUE	DEVIATION	Mean	Variance	95% Confidence		90/95 Tolerance	
0.1455	0.1455	0.1642	0.1525	0.1223						t*= 1.70	F*=2.47		
0.1521	0.1603	0.1851	0.1603	0.1215									
0.1475	0.1628	0.1814	0.1711	0.1115	RUN-IN	0.1633	0.0150					0.2040	
0.1565	0.1674	0.1961		0.1034		0.1006	XXXXXXXXXXXXXX					0.1226	
0.1432	0.1316	0.1269	0.0990	0.1153									
0.1262	0.1297	0.1227	0.1156	0.1180									
0.1208	0.1324	0.1339	0.1339	0.1123	DESIGN	0.1291	0.0122	0.6278	1.5004				
0.1313	0.1368	0.1527		0.1084		0.1067	XXXXXXXXXXXXXX	No	No			0.1623	
0.0990	0.1083	0.1083	0.0943	0.0990									
0.0956	0.1074	0.1121	0.1074	0.1132									
0.1030	0.1169	0.1231	0.1300	0.1138	CYCLE3	0.1142	0.0145	0.2732	0.7147				
0.1179	0.1230	0.1379	0.1439	0.1062				No	No			0.1535	
				0.1045								0.0750	
Mean	0.1232	0.1353	0.1454	0.1388		0.1104							
Std Dev	0.0564	0.0589	0.0658	0.0672		0.0072							

DATA SET 46-50		Alloy Code T				MEAN		TEST for Variance		90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	VALUE	STD DEVIATION	Mean	95% Confidence	t*= 1.68	F*=1.98
0.1039	0.1039	0.1112	0.1088	0.1015	0.1160	RUN-IN	0.1166	0.0092	= 0.505		
0.1124	0.1062	0.1148	0.1087	0.1087	0.1120	RUN-IN	0.1166	0.0092		0.1392	0.0939
0.1184	0.1168	0.1160	0.1120	0.1160	0.1168	RUN-IN	0.1166	0.0092			
0.1273	0.1255	0.1185	0.1168	0.1215	0.1267	XXXXXXXXXXXXXX					
0.1324	0.1358	0.1253	0.1253	0.1253	0.1267	XXXXXXXXXXXXXX					
0.1088	0.0893	0.0966	0.1088	0.0869	0.0940						
0.1111	0.0952	0.0989	0.1209	0.1256	0.1029	DESIGN	0.1123	0.0142			
0.1152	0.1012	0.1063	0.1256	0.1180	0.1180						
0.1168	0.1145	0.1168	0.1308	0.1338	0.1267	XXXXXXXXXXXXXX					
0.1329	0.1226	0.1338	0.1338	0.1088	0.0942						
0.1137	0.0966	0.1015	0.1099	0.0964	0.1027	CYCLE3	0.1145	0.0146			
0.1185	0.0989	0.0927	0.1176	0.1087	0.1021						
0.1232	0.1071	0.1156	0.1250	0.1145	0.1133						
0.1279	0.1133	0.1239	0.1382	0.1285	0.1387						
Mean	0.1201	0.1101	0.1132	0.1194	0.1097						
Std Dev	0.0100	0.0131	0.0147	0.0100	0.0134						

DATA SET 51-55		Alloy Code AZ				MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5						
0.0963	0.0868	0.0805	0.0900	0.0868						
0.0951	0.0872	0.0920	0.0824	0.0856						
0.0909	0.0844	0.0791	0.0844	0.0877	RUN-IN	0.0864	0.0049			
0.0904	0.0847	0.0782	0.0831	0.0896						
0.0892	0.0835	0.0769	0.0873	0.0873	XXXXXXXXXXXXXX					
0.0805	0.0741	0.0741	0.0773	0.1026						
0.0776	0.0888	0.0745	0.0776	0.0681						
0.0834	0.0791	0.0758	0.0877	0.0791	DESIGN	0.0813	0.0072			
0.0814	0.0806	0.0749	0.0872	0.0855						
0.0867	0.0841	0.0756	0.0867	0.0905	XXXXXXXXXXXXXX					
0.0709	0.0805	0.0741	0.0773	0.0741						
0.0745	0.0808	0.0633	0.0776	0.0713						
0.0834	0.0898	0.0726	0.0887	0.0801	CYCLE3	0.0812	0.0079			
0.0847	0.0888	0.0773	0.0896	0.0904						
0.0886	0.0886	0.0789	0.0924	0.0924						
Mean	0.0849	0.0841	0.0765	0.0846						
Std Dev	0.0072	0.0044	0.0058	0.0051	0.0089					

DATA SET 56-60		Alloy Code AR1		STUD5		MEAN VALUE		STD DEVIATION		TEST for Variance		9095 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	MEAN	VALUE	STD	DEVIATION	Mean	95% Confidence	t*= 1.68	F*=1.98
0.1195	0.1289	0.1195	0.0934	0.1108	0.1117	0.1117	0.1117	0.0099	0.0099	= 0.505	= 0.505	0.1352	0.0860
0.1243	0.1180	0.1095	0.0905	0.1073	0.1073	0.0987	0.1073	0.0099	0.0099				
0.1206	0.1132	0.0987	0.0979	0.1056	0.1056	0.1045	0.1045	0.0099	0.0099				
0.1199	0.1144	0.1045	0.0979	0.1090	0.1090	0.1072	0.1072	0.0099	0.0099				
0.1186	0.1195	0.1072	0.1037	0.1289	0.1289	0.1242	0.1242	0.0099	0.0099				
0.1195	0.1289	0.1242	0.0934	0.1222	0.1222	0.1272	0.1159	0.0099	0.0099				
0.1222	0.1272	0.1159	0.1117	0.1177	0.1177	0.1251	0.1221	0.0099	0.0099				
0.1251	0.1251	0.1221	0.1103	0.1211	0.1211	0.1243	0.1199	0.0099	0.0099				
0.1254	0.1243	0.1199	0.1199	0.1265	0.1265	0.1243	0.1274	0.0099	0.0099				
0.1291	0.1274	0.1169	0.1186	0.1256	0.1256	0.1382	0.1195	0.0099	0.0099				
0.1152	0.1382	0.1195	0.0804	0.1242	0.1242	0.1488	0.1138	0.1026	0.1026				
0.1159	0.1488	0.1138	0.1272	0.1214	0.1214	0.1221	0.1398	0.1118	0.1118				
0.1221	0.1398	0.1118	0.1206	0.1214	0.1214	0.1342	0.1166	0.1177	0.1177				
0.1166	0.1342	0.1177	0.1254	0.1214	0.1214	0.1414	0.1230	0.1186	0.1169				
0.1230	0.1414	0.1186	0.1326	0.1197	0.1197	Mean	0.1212	0.1286	0.1147	0.1045	0.1197	0.0087	0.0087
				Std Dev	0.0103	0.0103	0.0039	0.0103	0.0071	0.0120	0.0087		

DATA SET 61-65		Alloy Code MA				Alloy Code MA				Alloy Code MA				Alloy Code MA			
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	STUD7	STUD8	STUD9	STUD10	STUD11	STUD12	STUD13	STUD14	STUD15	STUD16	STUD17	
0.1253	0.1354	0.1404	0.1458	0.1253													
0.1230	0.1259	0.1412	0.1337	0.1312													
0.1265	0.1195	0.1369	0.1352	0.1456	RUN-IN												
0.1351	0.1273	0.1454	0.1454	0.1570													
0.1524	0.1391	0.1658	0.1617	0.1761	XXXXXXXXXXXXXX												
0.1253	0.1051	0.1253	0.1203	0.1203													
0.1145	0.1173	0.1230	0.1173	0.1116													
0.1137	0.1152	0.1213	0.1213	0.1079	DESIGN												
0.1221	0.1208	0.1234	0.1299	0.1273													
0.1309	0.1370	0.1268	0.1494	0.1391	XXXXXXXXXXXXXX												
0.1152	0.1051	0.1253	0.1203	0.1152													
0.1063	0.1013	0.1173	0.1230	0.1063													
0.1021	0.1065	0.1213	0.1166	0.1123	CYCLE3												
0.1183	0.1118	0.1196	0.1247	0.1183													
0.1247	0.1257	0.1227	0.1432	0.1268													
Mean	0.1224	0.1195	0.1304	0.1325	0.1280												
Std Dev	0.0121	0.0122	0.0131	0.0138	0.0195												
DATA SET 61-65		Alloy Code MA				Alloy Code MA				Alloy Code MA				Alloy Code MA			
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	STUD7	STUD8	STUD9	STUD10	STUD11	STUD12	STUD13	STUD14	STUD15	STUD16	STUD17	
0.1253	0.1354	0.1404	0.1458	0.1253													
0.1230	0.1259	0.1412	0.1337	0.1312													
0.1265	0.1195	0.1369	0.1352	0.1456	RUN-IN												
0.1351	0.1273	0.1454	0.1454	0.1570													
*					XXXXXXXXXXXXXX												
0.1253	0.1051	0.1253	0.1203	0.1203													
0.1145	0.1173	0.1230	0.1173	0.1116													
0.1137	0.1152	0.1213	0.1213	0.1079	DESIGN												
0.1221	0.1208	0.1234	0.1299	0.1273													
0.1152	0.1051	0.1253	0.1203	0.1152													
0.1063	0.1013	0.1173	0.1230	0.1063													
0.1021	0.1065	0.1213	0.1166	0.1123	CYCLE3												
0.1183	0.1118	0.1196	0.1247	0.1183													
Mean	0.1190	0.1159	0.1284	0.1278	0.1232												
Std Dev	0.0092	0.0105	0.0097	0.0102	0.0154												

\* Excludes the highest torque increment, see discussion under the Monel K-500 section of Phase II Test Results.

DATA SET 66-70		Alloy Code AM				STUD5				MEAN VALUE				STD DEVIATION				TEST for Variance				90/95 Tolerance		
STUD1	STUD2	STUD3	STUD4	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	t* = 1.68	F* = 1.98	t* = 0.505	0.1222	0.0752
0.0905	0.0933	0.0988	0.0960	0.0738																				
0.0965	0.1063	0.1021	0.1035	0.0854																				
0.1057	0.1047	0.1094	0.1132	0.0867	RUN-IN					0.0987														
0.0990	0.1060	0.1011	0.1108	0.0849																				
0.1029	0.1013	0.1013	0.1066	0.0876	XXXXXXXXXXXXXX																			
0.0960	0.0933	0.0933	0.0905	0.0905																				
0.1063	0.0924	0.1035	0.0965	0.0965																				
0.1085	0.1057	0.1123	0.1085	0.0952	DESIGN					0.1028														
0.1101	0.1108	0.1094	0.1087	0.0956																				
0.1120	0.1120	0.1130	0.1120	0.0970	XXXXXXXXXXXXXX																			
0.0933	0.0905	0.0849	0.0877	0.0905																				
0.1063	0.0993	0.0955	0.0938	0.0910																				
0.1057	0.1132	0.1057	0.1142	0.1009	CYCLE3					0.1027														
0.1108	0.1143	0.1046	0.1129	0.0997																				
0.1146	0.1136	0.1093	0.1146	0.0986																				
Mean	0.1039	0.1038	0.0993	0.1046	0.0916																			
Std Dev	0.0073	0.0084	0.0169	0.0093	0.0093																			

DESIGN

vs RUN-IN

DESIGN

vs CYCLE 3

DESIGN

DATA SET 71-75		Alloy Code AS															
STUD1	STUD2	STUD3	STUD4	STUD5	STUD6	STUD7	STUD8	STUD9	STUD10	STUD11	STUD12	STUD13	STUD14	STUD15	STUD16	STUD17	
0.0987	0.0987	0.0587	0.0855	0.0865	0.0865	0.0901	0.0910	0.0910	0.0910	0.0949	0.0949	0.0949	0.0949	0.0949	0.0949	0.0949	
0.1019	0.1182	0.0703	0.0726	0.0726	0.0726	0.0790	0.0790	0.0790	0.0790	0.0812	0.0812	0.0812	0.0812	0.0812	0.0812	0.0812	
0.1154	0.1134	0.0933	0.1019	0.1019	0.1019	0.1019	0.1019	0.1019	0.1019	0.0949	0.0949	0.0949	0.0949	0.0949	0.0949	0.0949	
ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
0.0987	0.0977	0.0669	0.0669	0.0660	0.0660	0.0734	0.0734	0.0734	0.0734	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	
0.0953	0.0859	0.0655	0.0655	0.0655	0.0655	0.0834	0.0834	0.0834	0.0834	0.0887	0.0887	0.0887	0.0887	0.0887	0.0887	0.0887	
0.1104	0.1043	0.0860	0.0860	0.0860	0.0860	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	XXXXXX	
0.1118	0.0587	0.0651	0.0651	0.0651	0.0651	0.0659	0.0659	0.0659	0.0659	0.0731	0.0731	0.0731	0.0731	0.0731	0.0731	0.0731	
0.0981	0.0531	0.0684	0.0684	0.0684	0.0684	0.0631	0.0631	0.0631	0.0631	0.0890	0.0890	0.0890	0.0890	0.0890	0.0890	0.0890	
0.1060	0.0699	0.0790	0.0790	0.0790	0.0790	0.0804	0.0804	0.0804	0.0804	0.0758	0.0758	0.0758	0.0758	0.0758	0.0758	0.0758	
ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
Mean	0.1040	0.0889	0.0726	0.0778	0.0830					0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	0.0181	
Std Dev	0.0071	0.0235	0.0112	0.0146	0.0108					No	No	No	No	No	No	No	

MEAN  
 VALUE  
 STD DEVIATION  
 TEST for  
 Variance  
 95% Confidence  
 t\*= 1.70      F\*=2.35  
 = 0.426

DESIGN vs RUN-IN  
 t      F  
 0.1624      1.2516  
 No      No

DESIGN vs CYCLE 3  
 t      F  
 0.1432      0.6211  
 No      No

DATA SET 76-80		Alloy Code	IMC3		MEAN	STD	TEST for	TEST for
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	Variance
0.1082	0.1034	0.1082	0.1034	0.0986	0.0986		95% Confidence	
0.0962	0.0986	0.0962	0.0962	0.0941	0.0941		$t^* = 1.68$	
0.0990	0.0974	0.0974	0.1022	0.0860	RUN-IN	0.1008	$F^* = 1.98$	
0.0985	0.1070	0.1021	0.1021	0.0936		0.0076		0.1197
0.1053	0.1182	0.1132	0.1092	0.0964	XXXXXXXXXXXXXXXXXXXXXX			0.0820
0.0986	0.0937	0.1082	0.0989	0.0989				
0.0965	0.0841	0.0889	0.0792	0.0744				
0.0795	0.0893	0.0795	0.0763	0.0747	DESIGN	0.0884		
0.0987	0.0936	0.0899	0.0875	0.0789				
0.0924	0.1033	0.0983	0.0983	0.0984	XXXXXXXXXXXXXXXXXXXXXX			
0.0889	0.0889	0.0889	0.0937	0.0937				
0.0841	0.0841	0.0744	0.0841	0.0792				
0.0763	0.0779	0.0779	0.0763	0.0747	CYCLE3	0.0850		
0.0638	0.0638	0.0875	0.0875	0.0789				
0.0864	0.0934	0.0944	0.0973	0.0894				
Mean	0.0915	0.0944	0.0937	0.0922	0.0853			
Std Dev	0.0093	0.0106	0.0115	0.0103	0.0082			

DATA SET 81-85		Alloy Code	IMC2	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5					
0.1179	0.1228	0.1179	0.1324	0.1373					
0.1107	0.1035	0.0986	0.1011	0.1107					
0.1103	0.0974	0.0990	0.1038	0.1103	RUN-IN	0.1109	0.0098	$t^*= 1.68$	0.1352
0.1119	0.1070	0.1009	0.1095	0.1095				$F^*= 1.98$	0.0866
0.1201	0.1082	0.1063	0.1112	0.1132	XXXXXXXXXXXXXX			$= 0.505$	
0.0840	0.0986	0.0937	0.0986	0.0889					
0.0744	0.0792	0.0841	0.0865	0.0841					
0.0860	0.0828	0.0876	0.0941	0.0909	DESIGN	0.0912	0.0077	$t^*$	0.1103
0.0838	0.0924	0.0972	0.0960	0.0972				$F$	0.0720
0.0934	0.0993	0.0983	0.1053	0.1023	XXXXXXXXXXXXXX			$F$	
0.0695	0.0840	0.0840	0.0986	0.0889					
0.0647	0.0720	0.0768	0.0841	0.0841					
0.0638	0.0795	0.0828	0.0925	0.0925	CYCLE3	0.0872	0.0113	$t^*$	0.1152
0.0891	0.0911	0.0924	0.1009	0.0997				$F$	0.0592
0.0874	0.0983	0.0964	0.1043	0.1063					
Mean	0.0969	0.0944	0.0944	0.1013					
Std Dev	0.0187	0.0134	0.0104	0.0115					

90/95 Tolerance										
DATA SET 86-90		Alloy Code IMA		STUD5		STUD4		STUD3		STUD1
		MEAN	STD	DEVIATION	MEAN	STD	DEVIATION	MEAN	STD	TEST for
0.1663	0.0923	0.1154	0.1016	0.0969	0.1139	0.1087	0.1166	0.1281	0.1377	RUN-IN
0.1376	0.0962	0.1139	0.1087	0.1166	0.1217	0.1377	0.1223	0.1413	0.1532	
0.1345	0.1039									
0.1330	0.1093									
ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	XXXXXX
0.1154	0.0784	0.0969	0.1016	0.1016	0.0985	0.1061	0.1061	0.1039	0.1233	DESIGN
0.1192	0.0824									
0.1185	0.0999									
0.1259	0.1033	0.1140	0.1188	0.1366	0.1093	0.1140	0.1078	0.1140	0.1040	DESIGN vs RUN-IN
ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	
0.1108	0.0599	0.0877	0.1201	0.0831	0.0993	0.1087	0.0962	0.1265	0.1121	CYCLE3
0.1061	0.0719									
0.1137	0.0885	0.0965	0.1121	0.1178	0.1093	0.1330	0.1259	0.1368	0.1416	
0.1093	0.1057									
0.1246	0.1152	0.1161	0.1416							
Mean	0.1244	0.0929	0.1081	0.1178	0.1177					
Std Dev	0.0165	0.0160	0.0143	0.0135	0.0208					

DATA SET 91-95		Alloy Code IMB		STUD3		STUD4		STUD5		MEAN	STD	TEST for	TEST for
STUD1	STUD2									VALUE	DEVIATION	Mean	Variance
0.1769	0.1373			0.2103		0.1505		0.2385					
0.1749	0.1575			0.1906		0.1339		0.2657					
0.1820	0.1594			0.1935		0.1317		ERR	RUN-IN	0.1756	0.0399		
ERR	ERR			ERR		ERR		ERR					
ERR	ERR			ERR		ERR		ERR	XXXXXXXXXXXXXX				
0.1307	0.1009			0.1249		0.1009		0.1808					
0.1433	0.1134			0.1149		0.0964		0.2032					
0.1451	0.1348			0.1286		0.1047		0.2047	DESIGN	0.1335	0.0314		
0.1472	0.1357			0.1357		0.1121		ERR	XXXXXXXXXXXXXX				
ERR	ERR			ERR		ERR		ERR					
0.1249	0.1042			0.1009		0.0782		0.1472					
0.1323	0.1244			0.1049		0.0905		0.1591					
0.1389	0.1379			0.1203		0.0985		0.1671	CYCLE3	0.1222	0.0238		
0.1468	0.1344			0.1282		0.1028		ERR					
ERR	ERR			ERR		ERR		ERR					
Mean	0.1494			0.1309		0.1412		0.1104		0.1958			
Std Dev	0.0197			0.0190		0.0383		0.0197		0.0407			

90/95 Tolerance

95% Confidence

t\*= 1.70

F\*=2.29

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

0.2854

0.0657

DATA SET 96-100		Alloy Code MK					TEST for Variance				
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	95% Confidence	
0.1056	0.1186	0.1089	0.1154	0.1056						$t^* = 1.68$	
0.1012	0.1142	0.0931	0.1093	0.0979						$F^* = 1.98$	
0.1011	0.1165	0.0934	0.1055	0.1011	RUN-IN	0.1046	0.0073				
0.1014	0.1145	0.0972	0.1047	0.0997							
0.1017	0.1108	0.0958	0.1036	0.0984	XXXXXXXXXXXXXX						
0.0959	0.1154	0.1056	0.1056	0.1089							
0.0963	0.1142	0.1028	0.0931	0.0963							
0.0956	0.1077	0.1000	0.0901	0.1022	DESIGN	0.0994	0.0070				
0.0980	0.1014	0.0980	0.0896	0.0980							
0.0932	0.0977	0.0951	0.0906	0.0938	XXXXXXXXXXXXXX						
0.0894	0.1024	0.0927	0.0894	0.0991							
0.0963	0.0931	0.0914	0.0898	0.0931							
0.1000	0.0912	0.0868	0.0868	0.0934	CYCLE3	0.0913	0.0059				
0.0997	0.0880	0.0829	0.0838	0.0905							
0.1004	0.0880	0.0800	0.0841	0.0899							
Mean	0.0984	0.1049	0.0949	0.0961	0.0979						
Std Dev	0.0040	0.0111	0.0079	0.0101	0.0053						

DATA SET 101, 102		Alloy Code MS	STUD3	STUD4	STUD5
STUD1	STUD2				
0.1121	0.1186	0.0000	0.0000	0.0000	0.0000
0.1175	0.1110	0.0000	0.0000	0.0000	0.0000
0.1275	0.1187	0.0000	0.0000	0.0000	RUN-IN
0.1330	0.1242	0.0000	0.0000	0.0000	
0.1397	0.1335	0.0000	0.0000	0.0000	XXXXXXXX
0.0862	0.0829	0.0000	0.0000	0.0000	
0.0979	0.0947	0.0000	0.0000	0.0000	
0.1033	0.0934	0.0000	0.0000	0.0000	DESIGN
0.1081	0.1014	0.0000	0.0000	0.0000	
0.1088	0.1049	0.0000	0.0000	0.0000	XXXXXXXX
0.0894	0.0862	0.0000	0.0000	0.0000	
0.0947	0.0963	0.0000	0.0000	0.0000	
0.0956	0.0978	0.0000	0.0000	0.0000	CYCLE3
0.0989	0.0997	0.0000	0.0000	0.0000	
0.1023	0.1023	0.0000	0.0000	0.0000	
Mean	0.1077	0.1044	0.0000	0.0000	0.0000
Std Dev	0.0158	0.0142	0.0000	0.0000	0.0000

DATA SET 106,107 Alloy Code MI		STUD1	STUD2	STUD3	STUD4	STUD5
0.1186	0.1186	ERR	ERR	ERR	ERR	ERR
0.1175	0.1158	ERR	ERR	ERR	ERR	ERR
0.1308	0.1319	ERR	ERR	ERR	ERR	RUN-IN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXX
0.1154	0.1121	ERR	ERR	ERR	ERR	ERR
0.1093	0.1093	ERR	ERR	ERR	ERR	ERR
0.1220	0.1231	ERR	ERR	ERR	ERR	DESIGN
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	XXXXXX
0.0927	0.1218	ERR	ERR	ERR	ERR	ERR
0.0947	0.1126	ERR	ERR	ERR	ERR	ERR
0.1099	0.1220	ERR	ERR	ERR	ERR	CYCLE3
ERR	ERR	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR	ERR
Mean	0.1123	0.1186	ERR	ERR	ERR	ERR
Std Dev	0.0124	0.0070	ERR	ERR	ERR	ERR

Mean  
Std Dev

DATA SET 111,112 Alloy Code MCU					
STUD1	STUD2	STUD3	STUD4	STUD5	
0.1347	0.1403	ERR	ERR	ERR	ERR
0.1154	0.1186	ERR	ERR	ERR	ERR
0.1167	0.1231	ERR	ERR	ERR	RUN-IN
0.1175	0.1288	ERR	ERR	ERR	ERR
0.1232	0.1375	ERR	ERR	ERR	XXXXXXXXXXXXXX
0.1065	0.1234	ERR	ERR	ERR	ERR
0.0894	0.1056	ERR	ERR	ERR	ERR
0.0820	0.1058	ERR	ERR	ERR	DESIGN
0.0865	0.1093	ERR	ERR	ERR	
0.0932	0.1153	ERR	ERR	ERR	XXXXXXXXXXXXXX
0.0895	0.1178	ERR	ERR	ERR	ERR
0.0959	0.1024	ERR	ERR	ERR	
0.0907	0.0972	ERR	ERR	ERR	CYCLE3
0.0914	0.1028	ERR	ERR	ERR	
0.0906	0.1036	ERR	ERR	ERR	
Mean	0.1015	0.1154	ERR	ERR	ERR
Std Dev	0.0160	0.0132	ERR	ERR	ERR

DATA SET 116, 117 Alloy Code MH				
STUD1	STUD2	STUD3	STUD4	STUD5
0.1478	0.1348	ERR	ERR	ERR
0.1337	0.1337	ERR	ERR	ERR
0.1385	0.1440	ERR	ERR	RUN-IN
0.1338	0.1451	ERR	ERR	ERR
0.1310	0.1496	ERR	ERR	XXXXXXXXXXXXXX
0.1024	0.1121	ERR	ERR	ERR
0.0931	0.1044	ERR	ERR	ERR
0.0989	0.1132	ERR	ERR	DESIGN
0.1039	0.1177	ERR	ERR	ERR
0.1114	0.1222	ERR	ERR	XXXXXXXXXXXXXX
0.0862	0.1024	ERR	ERR	ERR
0.0865	0.1012	ERR	ERR	ERR
0.0945	0.1088	ERR	ERR	CYCLE3
0.1056	0.1121	ERR	ERR	ERR
0.1095	0.1160	ERR	ERR	ERR
Mean	0.1118	0.1212	ERR	ERR
Std Dev	0.0201	0.0162	ERR	ERR

DATA SET 121-125		Alloy Code	ICR	STUD3	STUD4	STUD5	MEAN	STD	TEST for	TEST for
STUD1	STUD2						VALUE	DEVIATION	Mean	Variance
0.1131	0.1034		0.1131	0.0986	0.1034	0.1035	0.1034	0.0066	t= 1.68	95% Confidence
0.1059	0.1035		0.1011	0.0865	0.1035	0.1038	0.1034	0.0066	F*=1.98	= 0.565
0.1087	0.1022		0.1022	0.0925	0.1038	RUN-IN	0.1043	0.0066		
0.1119	0.1046		0.1034	0.0972	0.1034					
0.1182	0.1073		0.1092	0.1033	0.1082	XXXXXXXXXXXXXX				
0.1131	0.1034		0.0792	0.0937	0.1131					
0.1107	0.0986		0.0744	0.0720	0.0914					
0.1200	0.0957		0.0763	0.0714	0.0925	DESIGN	0.0948	0.0165	t	F
0.1229	0.0985		0.0813	0.0728	0.0924				No	0.1597
0.1251	0.1023		0.0934	0.0775	0.0983	XXXXXXXXXXXXXX			Yes	0.1355
0.0986	0.1034		0.0889	0.0986	0.1034					
0.0914	0.0986		0.0792	0.0841	0.0914					
0.0925	0.1022		0.0763	0.0812	0.0925	CYCLE3	0.0931	0.0089	t	F
0.0948	0.1021		0.0826	0.0826	0.0948				No	3.4423
0.1082	0.1053		0.0934	0.0844	0.0973				Yes	0.1151
Mean	0.1090		0.1021	0.0903	0.0864		0.0993			0.0712
Sid Dev	0.0107		0.0030	0.0130	0.0105		0.0068			

DATA SET 131-135		Alloy Code II					90/95 Tolerance				
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN	STD	TEST for	TEST for	Variance	
						VALUE	DEVIATION	Mean	95% Confidence		
0.1421	0.1469	0.1469	0.1662	0.1662		0.1664	0.1591	0.1927	RUN-IN	0.0151	t* = 1.68 F* = 1.98
0.1325	0.1325	0.1640	0.1591	0.1664		0.1588	0.1726	0.1714			
0.1362	0.1394	0.1653	0.1653	0.1644		0.1756	0.1709	0.1766	XXXXXXXXXXXXXX		
0.1522	0.1571	0.1726	0.1726	0.1709		0.1766	XXXXXXXXXXXXXX	0.1261			
0.1662	0.1671	0.1756	0.1756	0.1709		XXXXXXXXXXXXXX		0.0097			
0.1276	0.1421	0.1324	0.1566	0.1276		XXXXXXXXXXXXXX		0.6754			
0.1107	0.1277	0.1204	0.1277	0.1277		XXXXXXXXXXXXXX					
0.1168	0.1314	0.1168	0.1265	0.1281	DESIGN	XXXXXXXXXXXXXX					
0.1082	0.1229	0.1229	0.1266	0.1315		XXXXXXXXXXXXXX					
0.1182	0.1182	0.1290	0.1231	0.1310		XXXXXXXXXXXXXX					
0.1131	0.1228	0.1228	0.1179	0.1276		XXXXXXXXXXXXXX					
0.1011	0.0986	0.1083	0.1035	0.1132		XXXXXXXXXXXXXX					
0.1006	0.0957	0.1087	0.1071	0.1119	CYCLE3	XXXXXXXXXXXXXX					
0.1070	0.0972	0.1082	0.1119	0.1119		XXXXXXXXXXXXXX					
0.1102	0.1063	0.1142	0.1182	0.1162		XXXXXXXXXXXXXX					
Mean	0.1228	0.1271	0.1339	0.1359		0.1400					
Std Dev	0.0194	0.0216	0.0245	0.0238		0.0269					

DESIGN vs RUN-IN

DESIGN vs CYCLE 3

DATA SET 136-140		Alloy Code SS		Studs 136-139 only		MEAN	STD	TEST for	TEST for
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	Variance	90/95 Tolerance
0.1293	0.1223	0.1362	0.1129	0.1176			t=1.70	F*=2.47	
0.1333	0.1333	0.1533	0.1309	0.1144					
0.1185	0.1285	0.1446	0.1285	0.1185	RUN-IN	0.1296	0.0104		
0.1157	0.1258	0.1313	ERR	0.1146					
ERR	ERR	ERR	ERR	0.1124	XXXXXXXXXXXXXX				
0.0990	0.0873	0.0966	0.0756	0.0733					
0.1003	0.1062	0.0908	0.0885	0.0861					
0.1022	0.1108	0.1038	0.1046	0.0902	DESIGN	0.0999	0.0106		
0.1084	0.1140	0.1101	ERR	0.0917					
ERR	ERR	ERR	ERR	0.0907	XXXXXXXXXXXXXX				
0.0709	0.0756	0.0826	0.0990	0.0756					
0.0838	0.0979	0.0861	0.1003	0.0779					
0.0842	0.1108	0.0950	0.1100	0.0797	CYCLE3	0.0967	0.0141		
0.1017	0.1157	0.1028	0.1207	0.0794					
ERR	ERR	ERR	ERR	0.0831					
Mean	0.1048	0.1107	0.1111	0.1071	0.0932				
Std Dev	0.0178	0.0170	0.0241	0.0174	0.0179				

DATA SET 141-145		Alloy Code T				STUD5				MEAN VALUE				STD DEVIATION				TEST for 95% Confidence Variance				90/95 Tolerance		
STUD1	STUD2	STUD3	STUD4	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5	STUD5
0.1064	0.1015	0.1064	0.1039	0.1088																				
0.1136	0.1062	0.1148	0.1050	0.1087																				
0.1168	0.1128	0.1216	0.1063	0.1144 RUN-IN	0.1147	0.0097																		
0.1139	0.1197	0.1273	0.1080	0.1150																				
0.1244	0.1267	0.1411	0.1134	0.1314 XXXXXXXXXXXXXXXXX																				
0.0991	0.0942	0.0966	0.0796	0.0918																				
0.0989	0.1038	0.1026	0.0829	0.0940																				
0.1038	0.1095	0.1216	0.0954	0.1038 DESIGN	0.1058	0.0141																		
0.1038	0.1174	0.1261	0.1019	0.1080																				
0.1121	0.1309	0.1392	0.1116	0.1176 XXXXXXXXXXXXXXXXX																				
0.0820	0.0966	0.1039	0.1015	0.1039																				
0.0903	0.1026	0.1075	0.0940	0.1050																				
0.0937	0.1071	0.1176	0.0987	0.1144 CYCLE3	0.1078	0.0136																		
0.0977	0.1226	0.1273	0.1038	0.1156																				
0.1052	0.1343	0.1377	0.1103	0.1221																				
<b>Mean</b>	0.1041	0.1124	0.1194	0.1011	0.1103																			
<b>Std Dev</b>	0.0110	0.0124	0.0140	0.0098	0.0102																			

DESIGN vs RUN-IN

*t* = 1.68  
*F*\* = 1.98  
= 0.505

DESIGN vs CYCLE 3

*t* = 1.68  
*F*\* = 1.98  
= 0.4683

Mean  
Std Dev

DATA SET 146-150							90/95 Tolerance														
STUD1	STUD2	Alloy Code AZ	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance	STUD1	STUD2	Alloy Code AZ	STUD3	STUD4	STUD5	MEAN VALUE	STD DEVIATION	TEST for Mean	TEST for Variance		
0.0931	0.1026	0.0900	0.1058	0.1090						0.0935	0.1078	0.0856	0.0840	0.1063							
											0.0930	0.1113	0.0898	0.0855	0.0984	RUN-IN	0.0966	0.0090	$t^* = 1.68$	$F^* = 1.98$	
											0.0962	0.1130	0.0896	0.0888	0.0954						= 0.505
											0.0936	0.1108	0.0911	0.0879	0.0917	XXXXXXXXXXXXXXXXXX					
											0.0773	0.0931	0.0773	0.0741	0.0773						
											0.0898	0.0951	0.0665	0.0776	0.0792						
											0.0877	0.0984	0.0780	0.0866	0.0855	DESIGN	0.0838	0.0088	$t$	$F$	
											0.0880	0.1011	0.0749	0.0872	0.0839						
											0.0848	0.1013	0.0756	0.0816	0.0828	XXXXXXXXXXXXXXXXXX					
											0.0805	0.1058	0.0709	0.0678	0.0773						
											0.0776	0.0935	0.0617	0.0649	0.0745						
											0.0887	0.0952	0.0726	0.0769	0.0791	CYCLE3	0.0807	0.0106	$t$	$F$	
											0.0896	0.0929	0.0732	0.0798	0.0782						
											0.0873	0.0936	0.0743	0.0816	0.0796						
Mean	0.0875	0.1010	0.0781	0.0820	0.0865					Std Dev	0.0061	0.0072	0.0092	0.0097	0.0110						

DATA SET 151-155		Alloy Code	AR1			MEAN	STD	TEST for	TEST for
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	95% Confidence	Variance
0.1108	0.1152	0.1242	0.1152	0.1242				$t^* = 1.68$	$F^* = 1.98$
0.1117	0.1159	0.1159	0.1138	0.1180					$= 0.505$
0.1073	0.1192	0.1221	0.1206	0.1132	RUN-IN	0.1167	0.0054		
0.1078	0.1210	0.1188	0.1221	0.1122					
0.1125	0.1178	0.1178	0.1291	0.1108	XXXXXXXXXXXXXXXXXXXXXX				
0.1065	0.1065	0.1021	0.1065	0.1108					
0.1095	0.1095	0.1050	0.1138	0.1138					
0.1044	0.1118	0.1103	0.1147	0.1073	DESIGN	0.1108	0.0045		
0.1100	0.1089	0.1122	0.1155	0.1089					
0.1143	0.1134	0.1169	0.1221	0.1151	XXXXXXXXXXXXXXXXXXXXXX				
0.1021	0.1065	0.1065	0.1108	0.1152					
0.1074	0.1095	0.1050	0.1138	0.1222					
0.1088	0.1162	0.1088	0.1118	0.1192	CYCLE3	0.1117	0.0051		
0.1067	0.1188	0.1078	0.1199	0.1111					
0.1116	0.1116	0.1108	0.1169	0.1125					
Mean	0.1088	0.1135	0.1123	0.1164	0.1143				
Std Dev	0.0032	0.0047	0.0067	0.0056	0.0048				

90/95 Tolerance

0.1301 0.1033

0.1301

0.1033

DESIGN vs RUN-IN

0.1220 0.0996

0.1220

0.0996

DESIGN vs CYCLE 3

0.14310

0.14310

0.0996

DESIGN vs RUN-IN  
 $t$  F  
 No No

DESIGN vs CYCLE 3  
 $t$  F  
 No No

DATA SET 156-160		Alloy Code MA				TEST for Variance				90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN	STD	TEST for Variance			
						VALUE	DEVIATION	Mean	95% Confidence		
0.0900	0.1152	0.1102	0.1102	0.1001					$t^*=1.68$		
0.0860	0.1088	0.0988	0.1063	0.0913					$F^*=1.98$		
0.0869	0.1094	0.1043	0.0999	0.0978	RUN-IN	0.1078	0.0133				
0.089	0.1118	0.1196	0.1092	0.1079							0.1408
0.1165	0.1175	0.1340	0.1360	0.1299	XXXXXXXXXXXXXX						0.0749
0.0900	0.1203	0.1102	0.1051	0.1152							
0.0888	0.1173	0.1038	0.0938	0.1063							
0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1064	0.0085				
0.1053	0.1105	0.1066	0.1053	0.0963							
0.1062	0.1072	0.1186	0.1186	0.1165	XXXXXXXXXXXXXX						
0.1051	0.0950	0.1001	0.1051	0.0950							
0.0913	0.0860	0.0988	0.1038	0.0963							
0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.1011	0.0084				
0.0976	0.0989	0.0976	0.1118	0.1028							
0.1083	0.1000	0.1134	0.1144	0.1155							
Mean	0.0976	0.1059	0.1077	0.1090	0.1053						
Std Dev	0.0091	0.0111	0.0102	0.0095	0.0104						
DATA SET 156-160		Alloy Code MA				TEST for Variance				90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5		MEAN	STD	TEST for Variance			
						VALUE	DEVIATION	Mean	95% Confidence		
0.0900	0.1152	0.1102	0.1102	0.1001					$t^*=1.74$		
0.0860	0.1088	0.0988	0.1063	0.0913					$F^*=2.27$		
0.0869	0.1094	0.1043	0.0999	0.0978	RUN-IN	0.1031	0.0094				
0.0989	0.1118	0.1196	0.1092	0.1079							
*					XXXXXXXXXXXXXX						
0.0900	0.1203	0.1102	0.1051	0.1152							
0.0888	0.1173	0.1038	0.0938	0.1063							
0.0999	0.1065	0.1021	0.1065	0.1021	DESIGN	0.1046	0.0082				
0.1053	0.1105	0.1066	0.1053	0.0963							
0.1051	0.0950	0.1001	0.1051	0.0950							
0.0913	0.0860	0.0988	0.1038	0.0963							
0.0934	0.0836	0.0978	0.1094	0.1065	CYCLE3	0.0988	0.0072				
0.0976	0.0989	0.0976	0.1118	0.1028							
Mean	0.0944	0.1053	0.1041	0.1055							
Std Dev	0.0068	0.0119	0.0066	0.0049							

\* Excludes the highest torque increment, see discussion under the Monel K-500 section of Phase II Test Results.

DATA SET 161-165		Alloy Code AM		STUD5		MEAN VALUE		STD DEVIATION		TEST for 90/95 Tolerance	
STUD1	STUD2	STUD3	STUD4	STUD5						95% Confidence $t^*= 1.68$	Variance $F^*=1.98$ $= 0.505$
0.1044	0.0988	0.0933	0.0905	0.0877							
0.0965	0.1063	0.0938	0.0938	0.0910							
0.1009	0.1066	0.0943	0.0971	0.0933	RUN-IN	0.0967	0.0052				
0.0983	0.1046	0.0935	0.0976	0.0907							
0.1008	0.1018	0.0937	0.0965	0.0926	XXXXXXXXXXXXXX						
0.0794	0.0905	0.0877	0.0738	0.0766							
0.0812	0.0993	0.0924	0.0868	0.0840							
0.0924	0.1009	0.0962	0.0886	0.0867	DESIGN	0.0903	0.0074				
0.0969	0.1004	0.0907	0.0907	0.0892							
0.0959	0.0981	0.0997	0.0909	0.0892	XXXXXXXXXXXXXX						
0.0766	0.0933	0.0683	0.0794	0.0794							
0.0854	0.0938	0.0910	0.0910	0.0826							
0.0952	0.0943	0.0962	0.0943	0.0867	CYCLE3	0.0890	0.0072				
0.0914	0.0956	0.0907	0.0942	0.0864							
0.0915	0.0997	0.0909	0.0904	0.0870							
Mean	0.0925	0.0989	0.0915	0.0904							
Std Dev	0.0083	0.0048	0.0070	0.0065							
				0.0869							
				0.0047							



DATA SET 171 Only 1 Stud					
	STUD1	STUD2	STUD3	STUD4	STUD5
0.1276	0.0000	0.0000	0.0000	0.0000	0.0000
0.0962	0.0000	0.0000	0.0000	0.0000	0.0000
0.0909	0.0000	0.0000	0.0000	0.0000	0.0000 RUN-IN
0.0948	0.0000	0.0000	0.0000	0.0000	0.0000
0.1013	0.0000	0.0000	0.0000	0.0000	0.0000 XXXXXXXX
0.1082	0.0000	0.0000	0.0000	0.0000	0.0000
0.0962	0.0000	0.0000	0.0000	0.0000	0.0000
0.0990	0.0000	0.0000	0.0000	0.0000	0.0000 DESIGN
0.1009	0.0000	0.0000	0.0000	0.0000	0.0000
0.1053	0.0000	0.0000	0.0000	0.0000	0.0000 XXXXXXXX
0.0986	0.0000	0.0000	0.0000	0.0000	0.0000
0.0914	0.0000	0.0000	0.0000	0.0000	0.0000
0.0941	0.0000	0.0000	0.0000	0.0000	0.0000 CYCLE3
0.1058	0.0000	0.0000	0.0000	0.0000	0.0000
0.1082	0.0000	0.0000	0.0000	0.0000	0.0000
Mean	0.1012	0.0000	0.0000	0.0000	0.0000
Std Dev	0.0092	0.0000	0.0000	0.0000	0.0000

DATA SET 176 Only 1 Stud						Alloy Code IMC3
STUD1	STUD2	STUD3	STUD4	STUD5		
0.1179	ERR	ERR	ERR	ERR	ERR	
0.1035	ERR	ERR	ERR	ERR	ERR	RUN-IN
0.1038	ERR	ERR	ERR	ERR	ERR	
0.1070	ERR	ERR	ERR	ERR	ERR	
0.1122	ERR	ERR	ERR	ERR	ERR	XXXXXXX
0.1179	ERR	ERR	ERR	ERR	ERR	
0.1083	ERR	ERR	ERR	ERR	ERR	
0.1022	ERR	ERR	ERR	ERR	ERR	DESIGN
0.0997	ERR	ERR	ERR	ERR	ERR	
0.1033	ERR	ERR	ERR	ERR	ERR	XXXXXXX
0.1082	ERR	ERR	ERR	ERR	ERR	
0.1011	ERR	ERR	ERR	ERR	ERR	
0.1006	ERR	ERR	ERR	ERR	ERR	CYCLE3
0.0997	ERR	ERR	ERR	ERR	ERR	
0.1023	ERR	ERR	ERR	ERR	ERR	
Mean	0.1059	ERR	ERR	ERR	ERR	
Std Dev	0.0061	ERR	ERR	ERR	ERR	

DATA SET 181 Only 1 Stud		Alloy Code IMA			
	STUD1	STUD2	STUD3	STUD4	STUD5
0.0784	0.0000	0.0000	0.0000	0.0000	0.0000
0.0824	0.0000	0.0000	0.0000	0.0000	0.0000
0.0999	0.0000	0.0000	0.0000	0.0000	RUN-IN
0.1117	0.0000	0.0000	0.0000	0.0000	
ERR	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
0.0784	0.0000	0.0000	0.0000	0.0000	
0.0847	0.0000	0.0000	0.0000	0.0000	
0.0985	0.0000	0.0000	0.0000	0.0000	DESIGN
0.1081	0.0000	0.0000	0.0000	0.0000	
ERR	0.0000	0.0000	0.0000	0.0000	XXXXXXXX
0.0923	0.0000	0.0000	0.0000	0.0000	
0.0985	0.0000	0.0000	0.0000	0.0000	
0.1079	0.0000	0.0000	0.0000	0.0000	CYCLE3
0.1117	0.0000	0.0000	0.0000	0.0000	
0.1114	0.0000	0.0000	0.0000	0.0000	
Mean	0.0972	0.0000	0.0000	0.0000	0.0000
Std Dev	0.0128	0.0000	0.0000	0.0000	0.0000

DATA SET 186 Alloy Code IMB					
STUD1	STUD2	STUD3	STUD4	STUD5	
0.1009	ERR	ERR	ERR	ERR	ERR
0.1102	ERR	ERR	ERR	ERR	ERR
0.1286	ERR	ERR	ERR	ERR	RUN-IN
0.1280	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	XXXXXX
0.1009	ERR	ERR	ERR	ERR	ERR
0.1063	ERR	ERR	ERR	ERR	ERR
0.1192	ERR	ERR	ERR	ERR	DESIGN
0.1207	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	XXXXXX
0.0782	ERR	ERR	ERR	ERR	ERR
0.0964	ERR	ERR	ERR	ERR	ERR
0.1089	ERR	ERR	ERR	ERR	CYCLE3
0.1191	ERR	ERR	ERR	ERR	ERR
ERR	ERR	ERR	ERR	ERR	ERR
Mean	0.1098	ERR	ERR	ERR	ERR
Std Dev	0.0145	ERR	ERR	ERR	ERR

DATA SET 191-195		Alloy Code	MK		MEAN	STD	TEST for	TEST for
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	Variance
0.1348	0.1186	0.1121	0.1380	0.1348	0.1348	0.0000	0.1348	0.0000
0.1256	0.1191	0.1093	0.1288	0.1272	0.1272	0.0000	0.1272	0.0000
0.1231	0.1253	0.1088	0.1253	0.1198	RUN-IN	0.1205	0.0087	0.505
0.1169	0.1210	0.1047	0.1202	0.1234				
0.1147	0.1172	0.1056	0.1160	0.1229	XXXXXXXXXXXXXX			
0.1186	0.1510	0.1154	0.1283	0.1251				
0.1256	0.1386	0.1142	0.1288	0.1142				
0.1242	0.1275	0.1121	0.1297	0.1132	DESIGN	0.0098	-0.0359	0.7783
0.1161	0.1314	0.1097	0.1242	0.1153				
0.1114	0.1272	0.1101	0.1191	0.1153	XXXXXXXXXXXXXX			
0.1121	0.1380	0.1154	0.1121	0.1186				
0.1223	0.1272	0.1175	0.1191	0.1240				
0.1187	0.1242	0.1198	0.1286	0.1286	CYCLE3	0.1211	0.0067	0.0242
0.1113	0.1250	0.1169	0.1258	0.1290			No	2.1413
0.1095	0.1185	0.1166	0.1210	0.1266			Yes	0.1044
Mean	0.1190	0.1273	0.1126	0.1243	0.1225			0.1377
Std Dev	0.0070	0.0093	0.0045	0.0065	0.0063			



DATA SET 201-205		Alloy Code	ICR		MEAN	STD	TEST for	TEST for
STUD1	STUD2	STUD3	STUD4	STUD5	VALUE	DEVIATION	Mean	Variance
0.1469	0.1131	0.1034	0.1082	0.1518			95% Confidence	90/95 Tolerance
0.1398	0.1011	0.0914	0.1011	0.1277			$t^* = 1.68$	
0.1352	0.1022	0.0925	0.1006	0.1265	RUN-IN	0.1155	$F^* = 1.98$	
0.1363	0.1021	0.0985	0.0997	0.1241				0.0701
0.1396	0.1082	0.1053	0.1013	0.1290	XXXXXXXXXXXXXXXXXXXX			
0.1228	0.1324	0.1034	0.1131	0.1131				
0.1107	0.1204	0.0914	0.0938	0.1035				
0.1071	0.1152	0.0925	0.0987	0.1006	DESIGN	0.1083		
0.1180	0.1131	0.0936	0.0997	0.1034				
0.1300	0.1172	0.1013	0.1033	0.1132	XXXXXXXXXXXXXXXXXXXX			
0.1034	0.1324	0.1082	0.1131	0.1179				
0.1059	0.1083	0.0986	0.0986	0.1035				
0.1119	0.1119	0.0990	0.1006	0.1038	CYCLE3	0.1087		
0.1119	0.1131	0.0985	0.1046	0.1046				
0.1241	0.1211	0.1043	0.1082	0.1102				
Mean	0.1230	0.1141	0.0988	0.1028	0.1155			
Std Dev	0.0143	0.0096	0.0055	0.0057	0.0141			

DESIGN vs RUN-IN

DESIGN vs CYCLE 3

DESIGN vs RUN-IN

DESIGN vs CYCLE 3

DESIGN vs RUN-IN

DESIGN vs CYCLE 3

DATA SET 206-210	Alloy Code A				MEAN	STD	TEST for	TEST for
	STUD1	STUD2	STUD3	STUD4				
0.1044	0.0988	0.1016	0.0988	0.0933				
0.1077	0.1063	0.1063	0.1077	0.1021				
0.1066	0.1085	0.1123	0.1076	0.1057 RUN-IN	0.1051	0.0044		
0.1066	0.1073	0.1115	0.1046	0.1046				
0.1034	0.1050	0.1136	0.1018	0.1024 XXXXXXXXXXXXXXXXXX				
0.0933	0.0933	0.0988	0.0877	0.0933				
0.1105	0.1035	0.1091	0.0965	0.1035				
0.1094	0.1086	0.1218	0.1057	0.1086 DESIGN	0.1055	0.0081		
0.1115	0.1136	0.1157	0.1039	0.1108				
0.1077	0.1120	0.1125	0.1018	0.1098 XXXXXXXXXXXXXXXXXX				
0.0905	0.0905	0.1016	0.0766	0.1016				
0.1105	0.0952	0.1119	0.0965	0.1063				
0.1142	0.1047	0.1161	0.0962	0.1057 CYCLE3	0.1045	0.0098		
0.1122	0.1080	0.1163	0.0983	0.1108				
0.1120	0.1104	0.1146	0.0992	0.1130				
Mean	0.1067	0.1042	0.1109	0.0989	0.1046			
Std Dev	0.0067	0.0069	0.0064	0.0081	0.0058			

90/95 Tolerance  
 STUD5  
 0.0933  
 0.1021  
 0.1057 RUN-IN  
 0.1051  
 0.0044  
 t\*= 1.68  
 F\*=1.98  
 = 0.505  
 0.1161  
 0.0942

DESIGN vs RUN-IN  
 STUD5  
 0.1035  
 0.1086 DESIGN  
 0.1055  
 0.0081  
 t  
 F  
 -0.0165  
 0.2976  
 No  
 Yes  
 0.1256  
 0.0855

DESIGN vs CYCLE 3  
 STUD5  
 0.1016  
 0.1063  
 0.1057 CYCLE3  
 0.1045  
 0.0098  
 t  
 F  
 0.0290  
 0.6837  
 No  
 No  
 0.1288  
 0.0802

DATA SET 211-215		Alloy Code T				MEAN VALUE	STD DEVIATION	TEST for 95% Confidence $t^* = 1.68$	TEST for Variance $F^* = 1.98$	90/95 Tolerance
STUD1	STUD2	STUD3	STUD4	STUD5						
0.1137	0.1282	0.1258	0.1258	0.1088						
0.1173	0.1320	0.1234	0.1295	0.1246						
0.1176	0.1384	0.1312	0.1384	0.1264 RUN-IN	0.1302	0.0117				
0.1191	0.1337	0.1418	0.1452	0.1244						
0.1309	0.1358	0.1577	0.1553	0.1290 XXXXXXXXXXXXXXXX						
0.1112	0.1331	0.1307	0.1282	0.1064						
0.1148	0.1283	0.1295	0.1418	0.1050						
0.1240	0.1288	0.1449	0.1481	0.1128 DESIGN	0.1330	0.0173				
0.1355	0.1314	0.1537	0.1543	0.1156						
0.1494	0.1397	0.1676	0.1657	0.1244 XXXXXXXXXXXXXXXX						
0.1064	0.1161	0.1331	0.1307	0.0991						
0.1160	0.1160	0.1369	0.1332	0.1050						
0.1368	0.1232	0.1441	0.1409	0.1128 CYCLE3	0.1324	0.0188				
0.1441	0.1267	0.1532	0.1498	0.1203						
0.1582	0.1397	0.1726	0.1642	0.1319						
Mean	0.1263	0.1301	0.1431	0.1434	0.1164					
Std Dev	0.0154	0.0074	0.0152	0.0128	0.0102					



## **Appendix D**

### **ANTI-SEIZING TEST RESULTS**

**TABLE 1 - ANTI-SEIZING TEST RESULTS**

LUBRICANT	TEST MATERIAL - TYPE 104 CRES										BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F					
	INITIAL RUN-IN					INITIAL BREAKAWAY					INSTALLATION					
	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B	
N5000	123	123	125	123	123	73	75	75	72	73	125	123	123	122	118	478
N1000	126	125	125	125	125	83	80	80	80	82	125	125	124	125	139	285
Neolube No. 650	124	125	125	125	125	67	79	70	75	75	127	125	124	126	148	299
NIKAL	125	125	125	125	125	89	86	89	89	86	125	126	125	125	159	540
N2000	125	124	125	125	125	78	77	81	80	80	125	124	124	127	125	263
Never Seez	125	124	126	125	125	79	81	81	80	80	125	124	127	125	128	343
NM-91	125	125	125	125	125	85	90	85	90	89	126	125	125	124	147	297
Molykote P37	125	125	125	125	125	81	90	82	86	86	125	125	125	125	119	199
MDSI	125	125	125	125	124	69	70	70	66	70	126	125	125	124	94	110
RLGMO	126	125	125	125	126	80	79	80	81	80	125	125	125	125	85	133

+ The needle on the torque wrench jumped indicating possible galling

**TABLE 2 - ANTI-SEIZING TEST RESULTS**

LUBRICANT	TEST MATERIAL - K-MONEL/MONEL										BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F				
	INITIAL RUN IN					BREAKAWAY TORQUE (ft-lbs)					EXPOSURE AT 650°F				
	1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B
N5000	175	175	175	175	175	95	100	95	95	97	177	175	175	175	175
N1000	175	175	175	175	176	102	105	101	100	102	180	175	175	176	177
Neolube No. 650	175	176	175	175	175	86	90	89	84	86	175	175	174	175	175
NKAL	176	175	175	175	131	129	127	130	127	178	175	175	176	178	178
N2000	176	175	176	177	175	101	104	99	90	97	174	176	175	175	174
Never Seez	175	174	175	174	175	100	95	99	99	98	175	175	175	176	177
NM-91	175	175	177	176	175	127	132	130	140	136	177	175	175	175	175
Molykote P37	174	175	176	174	116	116	119	121	117	175	176	174	175	175	175
MDSI	175	176	175	175	91	87	87	90	86	174	175	175	175	175	175
RLGMO	176	175	176	175	176	105	104	104	106	106	175	176	176	177	175

+ The needle on the torque wrench jumped indicating possible galling

TABLE 3 - ANTI-SEIZING TEST RESULTS

LUBRICANT	TEST MATERIAL	ALLOY STEEL										BREAKAWAY TORQUE (ft-lbs) AFTER X WEEKS OF EXPOSURE AT 650°F						
		INITIAL RUN IN					INITIAL BREAKAWAY					INSTALLATION			1	3	6	10
		1	3	6	10A	10B	1	3	6	10A	10B	1	3	6	10A	10B	A	B
N5000		230	230	230	230	231	155	135	150	150	160	230	230	230	232	275	321	284
N1000		230	230	230	230	230	150	151	150	151	155	231	229	230	232	227	338	245
Neolube		230	228	230	231	230	112	100	134	109	112	229	230	230	229	270	309	222
No.650																		248
NIKAL		237	230	234	231	230	194	175	186	170	170	236	230	229	230	230	515	482
																		450
N2000		228	231	230	231	230	138	148	145	145	148	232	230	234	230	229	240	281
Never Seez		231	232	229	234	230	150	152	141	154	157	232	230	230	231	261	401	390
NM-91		230	230	230	231	171	170	165	169	180	231	231	229	230	230	299	422	309
Molykote		228	231	229	230	232	151	160	157	156	157	228	230	230	231	230	244	250
P37																		263
MDSI		231	230	229	230	231	135	141	121	131	137	229	229	230	230	161	138	220
																		150
RLGMO		230	232	232	234	230	156	156	146	152	151	230	229	234	230	183	220	280
																+	+	256

+ The needle on the torque wrench jumped indicating possible galling

## **Appendix E**

### **ANTI-GALLING TEST RESULTS**

TABLE 1 - ANTI-GALLING TEST RESULTS

TEST MATERIAL & MONEL/MONEL TEST LOADS CYCLES 1-8 22300 LBS CYCLES 9-12 33500 LBS	INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)								NUMBER OF TORQUINGS TO GALLING				OTHER OBSERVATIONS
	1	2	3	4	5	6	7	8	9	10	11	12	
No Lubricant	295	*											2 Seized
N5000 -1	193	219	228	220	251	211	205	228	340	309	308	316	12
	-2	229	185	229	219	225	205	221	211	350	325	324	332 12
N1000 -1	190	205	209	212	206	202	210	203	310	307	352	323	12
	-2	240	218	245	221	239	222	220	222	380	348	352	338 12
Neolube -1	198	170	160	149	148	141	135	134	260	215	212	212	12 Coats uneven
No. 650 -2	132	130	118	115	114	110	110	120	189	213	222	231	12
NIKAL -1	320*	444*	416*	342*									1 Discontinued
	-2	303	375*	410*	355*								2 Discontinued
N2000 -1	233	195	178	175	216	219	193	203	360	352	338	301	12
	-2	224	215	220	222	229	233	232	238	313	311	326	330 12
Never -1	229	197	199	200	185	202	200	221	469	403	395	380	12
Seez -2	220	230	203	217	165	210	229	212	304	419	351	354	12
NM-91 -1	274	274	256	243	250	255	242	232	458	409	400	364	No Galling
	-2	320	284	284	254	272	260	245	249	439	369	330	312 No Galling
Molykote -1	211	209	210	210	209	211	221	210	380	403	360	350	12
P37 -2	221	225	231	222	238	231	220	220	372	389	358	360	12
MDSI -1	274	246	305	304	186	245	282	281	277	402	450	483	12
-2	221	192	239	276	223	235	251	315	332	382	462	494	12
RLGMO -1	168	158	148	142	139	135	152	136	244	221	243	262	12
-2	186	132	121	130	136	132	132	134	203	253	250	250	12

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 2 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: K-Mone/Monei/Monei		TEST LOADS: CYCLES 1-8 22300 IBS						CYCLES 9-12 33500 IBS						OTHER OBSERVATIONS
LUBRICANT/ SPECIMEN		1	2	3	4	5	6	7	8	9	10	11	12	
No Lubricant	*	*												Seized
N5000 -1	129	151	171	158	159	144	165	240	215	211	228			
	-2	142	139	134	149	135	140	138	140	220	220	212	233	
N1000 -1	138	149	150	151	149	149	150	149	210	219	231	221		
	-2	162	150	162	163	160	155	160	151	245	235	249	236	
Neolube -1	130	123	110	101	93	89	82	81	144	147	135	129		
	No. 650 -2	82	76	72	70	68	60	63	77	118	140	130	135	
NIKAL -1	247*	360*	380*	320*										Discontinued
	-2	205	279	350*	305*									Discontinued
N2000 -1	129	105	100	105	128	132	130	120	240	226	211	194		
	-2	138	128	136	135	142	149	141	145	199	182	195	200	
Never -1	165	140	149	142	134	145	135	151	325	294	294	279		
	Seez -2	161	169	138	150	112	140	163	157	218	265	249	253	
NM-91 -1	215	215	192	180	189	197	175	171	315	291	260	268		
	-2	239	220	205	189	211	199	185	340	265	233	225		
Molykote -1	140	140	131	133	142	139	139	137	259	238	228	228		
	P37 -2	170	166	161	160	168	161	154	151	260	269	250	237	
MDSI -1	182	159	168	178	135	185	189	219	185	255	296	333		
	-2	161	142	161	169	163	170	184	215	223	245	315	335	
RLGMO -1	120	110	100	95	90	90	95	100	160	139	163	162		
	-2	125	90	84	94	90	90	85	99	138	143	136	160	

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

**TABLE 3 - ANTI-GALLING TEST RESULTS**

TEST MATERIAL: Type 304 CRES	TEST LOADS: CYCLES 1-8 15600 lbs CYCLES 9-12 23400 lbs	INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)								NUMBER OF TORQUINGS TO GALLING	OTHER OBSERVATIONS
		1	2	3	4	5	6	7	8		
LUBRICANT/ SPECIMEN											
No Lubricant	285	342	500	338							2
N5000 -1 -2	215	204	192	179	188	180	170	165	370	285	261
	187	185	210	182	180	170	170	163	290	255	251
N1000 -1 -2	152	169	178	178	159	153	149	151	275	255	249
	179	155	158	160	160	157	155	156	263	236	224
Neolube -1	159	153	125	150	131	131	110	110	313	220	222
No. 650 -2	200	209	171	159	148	149	171	131	300*	249	224
NIKAL -1 -2	262	310*	315*	308*	345*	295*	270*				12
	303	298*	300*	289*	284*	294*					Discontinued
N2000 -1 -2	197	169	192	169	211	201	179	206	322	275	245
	232	182	182	172	202	194	195	191	339	269	268
Never -1 Seez -2	210	175	168	161	191	165	160	155	311	250	243
	191	192	174	181	217	208	196	188	410*	220	220
NM-91 -1 -2	95	186	193	190	209	189	189	182	342	259	252
	228	190	190	183	218	218	191	180	313	269	268
Molykote -1 P37 -2	206	195	180	185	170	171	165	170	380*	280	265
	167	154	150	141	162	161	167	165	285	275	263
MDSI -1 -2	219	270	255	222	178	178	182	190	319	418	460*
	175	160	178	180	220	232	270	279	435*	470*	460*
RLGMO -1 -2	163	170	152	128	163	126	132	125	220	219	172
	139	122	121	122	123	118	117	112	211	175	180

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 4 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Type 304 GRES		TEST LOADS: CYCLES 1-8 15600 lbs CYCLES 9-12 23400 lbs											
LUBRICANT/ SPECIMEN		BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb)				OTHER OBSERVATIONS							
		1	2	3	4	5	6	7	8	9	10	11	12
No Lubricant		400	245	265	245								
N5000	-1	140	155	150	135	135	130	120	275	220	190	180	
	-2	125	131	140	125	131	129	123	121	221	196	195	185
N1000	-1	105	110	103	110	114	115	111	109	164	159	154	156
	-2	121	109	100	98	106	112	112	102	178	181	167	166
Neolube	-1	116	115	95	89	109	90	86	78	204	149	118	120
No. 650	-2	*	*	130	123	100	102	120	99	300*	190	190	162
NIKAL	-1	170	220*	238*	259*	230*	236*	233*					Discontinued
	-2	209	265	262*	250*	211*	231*						Discontinued
N2000	-1	135	118	126	120	128	132	119	121	211	201	199	188
	-2	148	120	116	115	151	139	139	140	223	199	186	193
Never	-1	159	135	123	120	140	129	122	119	249	199	184	186
Seez	-2	142	155	131	134	180	169	162	148	970*	200	205	208
NM-91	-1	161	151	142	150	160	149	139	131	265	214	200	179
	-2	160	142	142	139	180	159	142	141	240	210	185	184
Molykote	-1	161*	160	142	150	140	130	126	132	350*	211	200	190
P37	-2	119	110	111	110	109	105	103	199	199	197	202	
MDSI	-1	162	200	160	139	135	111	100	99	219	275	298*	330*
	-2	132	112	121	140	171	205	202	203	264	271	250*	290*
RLGMO	-1	118	123	118	100	128	97	98	92	169	160	128	112
	-2	90	86	86	85	18	80	79	76	149	121	120	119

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 5 - ANTI-GALLING TEST RESULTS

TEST MATERIAL: Alloy Steel		TEST LOADS: CYCLES 1-8 @ 400 lbs CYCLES 9-12 @ 5000 lbs										NUMBER OF TORQUINGS TO GALLING		OTHER OBSERVATIONS	
LUBRICANT/ SPECIMEN		INSTALLATION TORQUE VALUE PER TORQUING CYCLE (ft-lb)													
		1	2	3	4	5	6	7	8	9	10	11	12		
No Lubricant	*													1	Seized
N5000	-1	250	228	221	216	221	210	213	333	365	380	389	389	12	
	-2	206	215	218	214	200	204	229	242	338	363	400	406	12	
N1000	-1	246	244	245	257	225	249	248	262	379	369	400	430	12	
	-2	215	274	270	260	214	230	224	214	342	366	393	406	12	
Neolube	-1	159	148	149	148	136	130	136	136	214	230	260	251	12	Deep Gouges
No. 650	-2	173	132	132	130	135	138	134	138	232	230	260	272	12	Deep Gouges
NIKAL	-1	298	300	301	290	318	323	322	334	530	578	545	548	12	
	-2	278	259	289	295	311	329	335	333	463	468	472	485	12	
N2000	-1	209	252	233	228	232	244	238	243	319	331	310	298	12	
	-2	235	224	235	220	247	220	236	254	368	388	363	393	12	
Never	-1	212	202	207	210	200	206	212	222	450	389	386	396	12	
Seez	-2	200	193	399	207	185	178	183	186	279	269	305	311	12	
NM-91	-1	227	223	208	201	230	219	208	205	388	391	357	351		No Galling
	-2	230	230	225	220	258	277	258	236	411	397	414	403		No Galling
Molykote	-1	202	199	199	214	233	202	202	398	353	349	349	349		No Galling
P37	-2	225	235	204	219	218	211	225	213	369	355	380	350		No Galling
MDSI	-1	292	328	340	369	264	343	384	417	372	421	545	600	12	
	-2	212	233	250	253	272	350	423	425	546	529	555	600	12	
RLGMO	-1	199	181	183	187	175	176	180	180	327	312	270	278		No Galling
	-2	200	189	189	180	173	172	169	170	328	304	292	277	12	

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.

TABLE 6 - ANTI-GALLING TEST RESULTS

TEST MATERIAL		TEST LOADS CYCLES 1-8 23400 lbs CYCLES 9-12 35000 lbs						OTHER OBSERVATIONS					
LUBRICANT/ SPECIMEN		BREAKAWAY TORQUE VALUE PER TORQUING CYCLE (ft-lb)											
		1	2	3	4	5	6	7	8	9	10	11	12
No Lubricant	*												Seized
N5000	-1	173	160	160	159	149	147	142	150	200	214	219	239
	-2	145	158	157	162	139	146	149	160	180	245	239	279
N1000	-1	180	178	179	173	166	162	174	180	219	240	252	282
	-2	160	190	200	200	154	168	173	168	220	244	269	248
Neolube	-1	110	98	92	88	80	72	80	80	122	138	142	142
No. 650	-2	99	78	73	71	88	91	88	82	120	129	148	161
NIKAL	-1	212	190	209	201	215	206	222	221	415	405	400	385
	-2	218	178	197	202	222	240	254	234	290	308	339	309
N2000	-1	151	162	178	168	152	157	162	182	193	204	220	205
	-2	160	165	178	170	165	160	160	168	246	253	260	263
Never	-1	150	148	150	155	140	151	156	167	321	261	289	271
Seez	-2	140	141	140	150	124	122	131	134	191	182	181	188
NM-91	-1	162	160	149	144	163	151	149	148	248	242	241	240
	-2	165	171	162	150	179	188	180	175	270	265	270	260
Molykote	-1	139	136	135	142	155	141	148	145	237	218	215	212
P37	-2	149	151	142	148	154	150	140	141	242	230	234	230
MDSI	-1	192	198	210	200	160	160	212	232	254	300	385	458
	-2	161	171	180	189	202	245	281	295	365	410	405	430
RLGMO	-1	141	133	135	131	125	122	122	205	209	199	200	
	-2	141	139	131	119	122	118	118	113	205	194	190	192

\* The needle on the torque wrench jumped accompanied by audible clicking indicating possible galling.